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Symposium on Environmental Conditions in the Newfoundland Grand Bank Area in 1972 and their Effect on Fishery Trends

Dartmouth • Canada
November 1975

Introduction

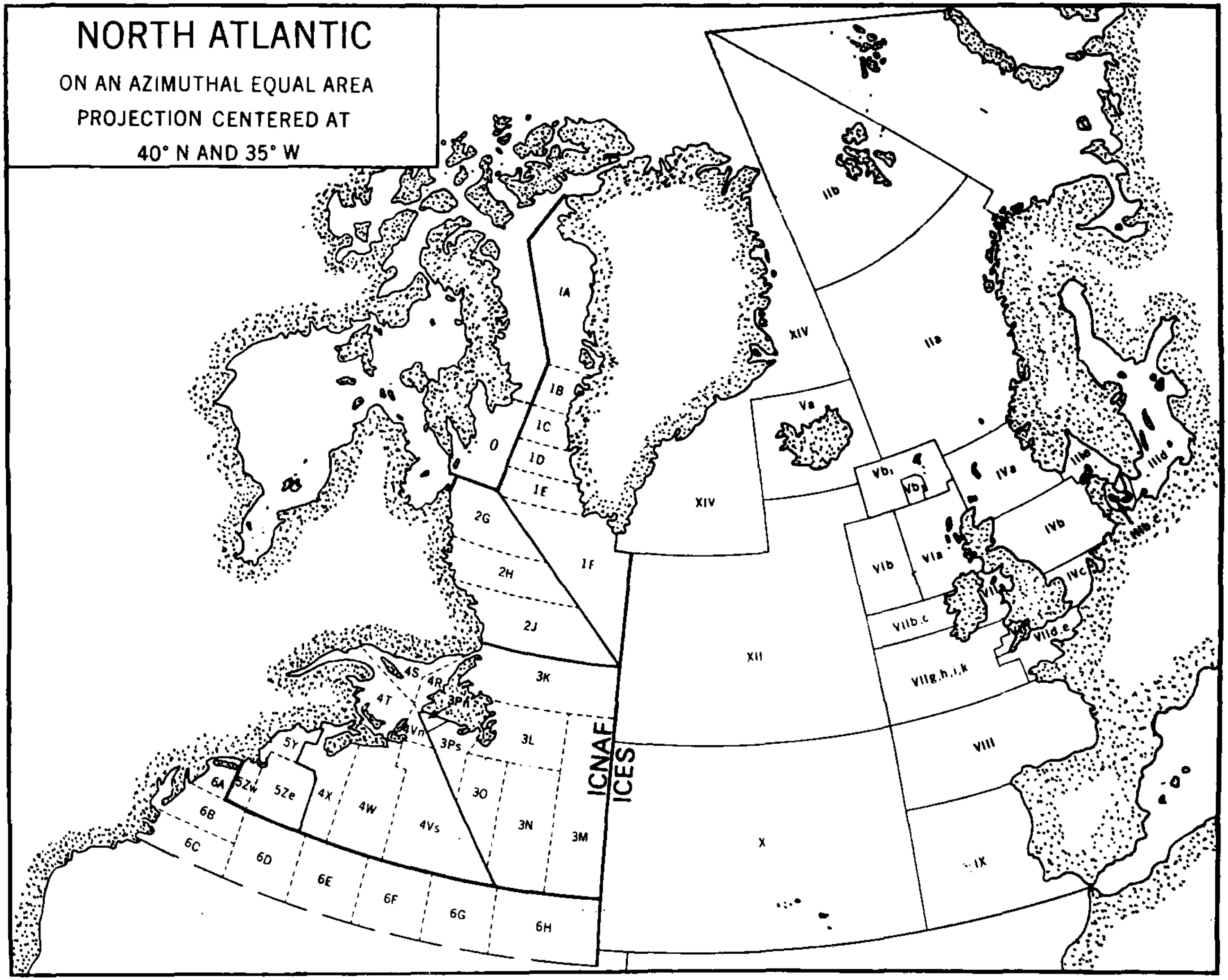
A Symposium on Environmental Conditions in the Newfoundland Grand Banks Area, 1972 and their Effect on Fishery Trends was organized by the International Commission for the Northwest Atlantic Fisheries (ICNAF) and held on 20 May 1974 at the Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada.

After a few opening remarks from the convener, Mr H.W. Hill (UK) and a welcome extended to all visitors by Dr W.L. Ford, Director of the Atlantic Oceanographic Laboratory, the convener continued by reminding the participants that the idea for a Symposium on Environmental Conditions in 1972 had originated during the previous meeting of the ICNAF Environmental Subcommittee in May 1973 in Copenhagen, when several papers and research reports by the USSR, Polish, Canadian and United kingdom delegates were presented describing work in the general area of the Newfoundland Grand Bank, a number of these papers indicating that anomalous conditions had prevailed. Thus it seemed that not only was there an unusually large research effort in the area in 1972, but also that environmental conditions were particularly interesting and worthy of further study. Hence it was decided to arrange this symposium.

The convener reviewed the programme briefly, explaining that Dr Woznick had recently been taken ill and hence was unable to present his paper on Polish work in the area during 1972, that since the USSR delegation had not yet arrived, he had arranged for the papers by Drs Burmakin and Kudlo to be presented by Drs Templeman and Clarke, and Dr Cushing had kindly offered to present the paper by Robinson, Colebrook and Cooper since none of these authors had been able to attend. The convener expressed his gratitude to Drs Templeman, Clarke and Cushing for their willing co-operation in reviewing and presenting these papers at short notice.

Office of the Secretariat
International Commission for the
Northwest Atlantic Fisheries
Dartmouth, Nova Scotia
Canada

20 May 1974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1972: An Unusual Year?

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Introduction

Sea surface temperatures observed by mariners have for many years formed the data base for a variety of research activities and atlas presentations. Bailey (1961) demonstrated the compatibility of standard hydrographic observations with the casual merchant ship sea surface temperature observations. These findings were conclusively supported by the summaries of oceanographic conditions in 1972 for the Northwest Atlantic as presented to the Annual Meeting of ICNAF in 1973.

Weekly analyses of sea surface temperature data from merchant ships have been completed in chart form since 1962. Now comprising over 600 diagrams, these charts form the basis on which statistical analyses may be carried out.

Initially, the statistical analyses were in essence an experiment to determine whether or not useful information might be extracted from this kind of data presentation. Since the extracted information proved to be stable, 13 points including two at coastal stations, were selected from which monthly mean data were extracted. These points, as shown in Fig. 1, were chosen as being representative of general water masses, locations of interest, and the four ocean stations, as points of reference for comparison with the statistical work of other investigators.

The use of data extracted from charts has several distinct advantages; namely, a very large number of points may be examined, actual observations do not always have to have been made, and the events surrounding a point can be reviewed at any time.

It is neither possible nor desirable to look at the results of all the different analyses for the 13 positions at this time. Furthermore, the sponsors of this Symposium have directed that attention be focused on conditions in the Grand Banks area.

Researchers reporting to ICNAF on observations taken in 1972 made a number of spectacular comments: "The temperatures are now back at the level of the mean values for the years 1876-1915 and the climatic jump-back to cold conditions has been just as sudden as the rise in temperatures in the twenties". "The cold water below -1.5°C (in the Labrador current) was about seven times as great as in the previous coldest year". Comments such as these and others, suggest that 1972 was a most unusual year.

It should be noted that the research documents on hydrographic conditions presented at the 1973 ICNAF Annual Meeting all showed remarkable agreement.

Seasonal Departures From Normal

Figures 2 to 5 show the departures from normal of air and sea surface temperatures for each season of 1972. The air temperature information is based on Thomas (1973), and the winter season of air temperature is based on a 3-month period commencing in December 1971. Because of a lag of approximately 30 days in corresponding sea surface temperatures, the winter season for these data was assumed to commence in January 1972.

Climatologists examining the Canadian weather scene in 1972 noted that:

a) "Weather reporting stations throughout the length and breadth of Canada reported colder than normal conditions during 1972. The weather in so vast a country such as Canada is so varied, that there is usually a balance, over the year, between areas with sligtly below normal and areas with slightly above normal temperatures". (Thomas, 1973)

b) "In the large north eastern area of Canada, 1972 was the coldest year on record. Other unusual years in recent decades were the almost nation-wide warm years of 1931 and 1953, and the cold years of 1933, 1950 and 1956, but in none of these was the entire country either warmer or colder than normal". (Thomas, 1973)

As seen in Fig. 2, the larger departures from normal air temperatures were centered over Baffin Island and covered most of Labrador during the winter season. The gradient was in a general north-south direction such that normal conditions were experienced in the Portland, Maine region, and higher than normal temperatures were observed in the vicinity of Cape Hatteras. Corresponding sea surface temperatures follow the same general pattern.

The sea surface temperatures in the Newfoundland area appear to be anomalous. However, at this season of the year the waters near Belle Isle (Position 6) are near the minimum (-1.8°C) and thus can show only positive departures. On the Grand Banks, the large departures reflect an abundance of the southward movement of Arctic waters well on to the Banks and hence show not only the effect of local cooling but also the advection of colder waters into the area.

During the spring (Fig. 3) the centre of cooler air temperatures was located over central Labrador and a relaxation in the intensity of the departure from normal had occurred. In the south, the centre of higher than normal departures had shifted westward such that the Cape Hatteras area was located in a region of sub-normal temperatures. On the ocean a two-fold pattern appears to have taken place. The cold waters are colder and more widespread caused by abnormally low winter temperatures and an increased flow of waters of Arctic origin. The warmer waters also appear to have possessed a greater flow

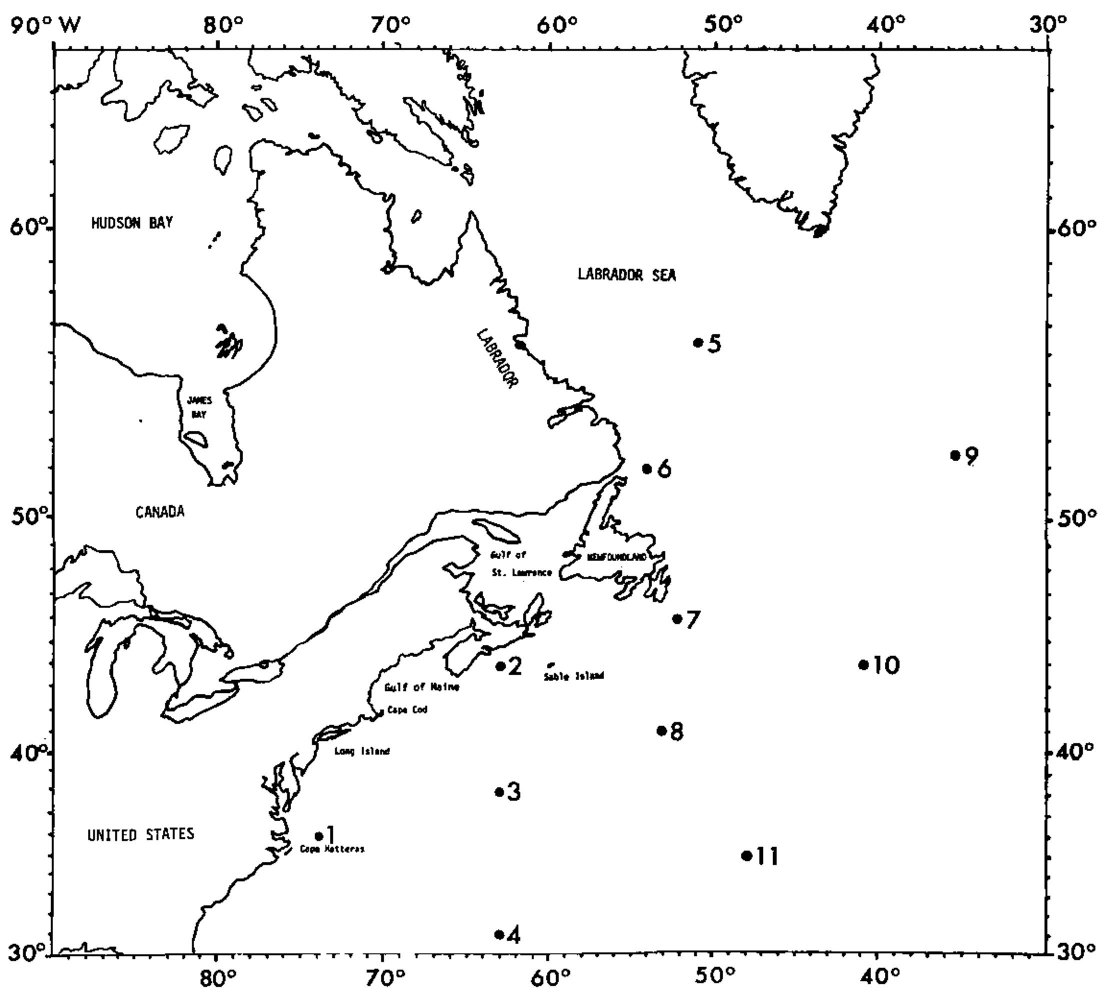

Fig. 1. Station locations.

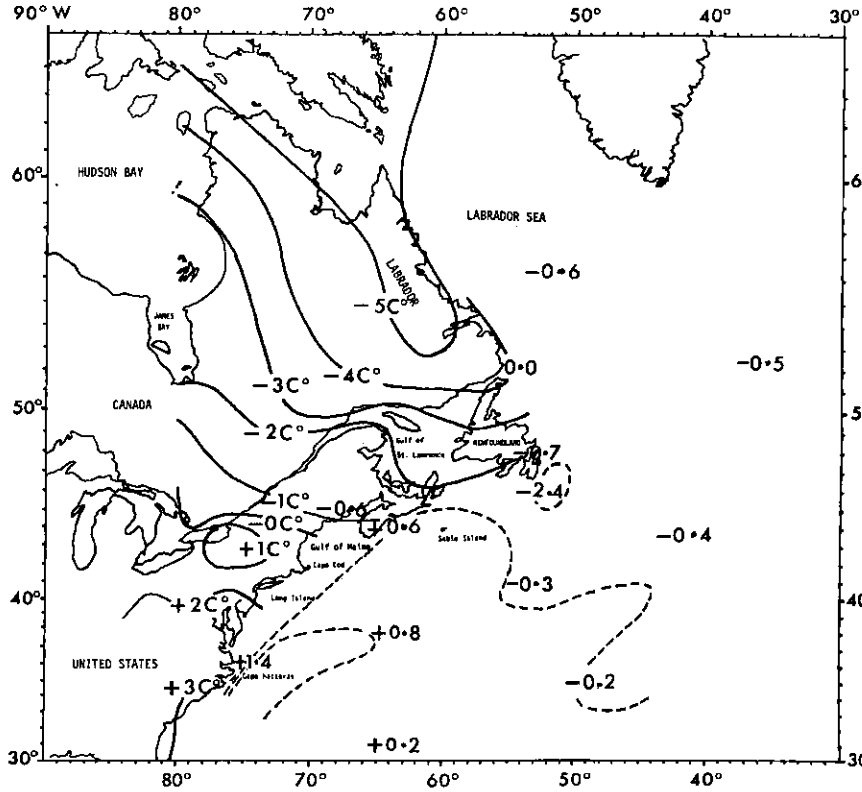

Fig. 2. Departures from normal of air and sea surface temperatures for winter 1972.

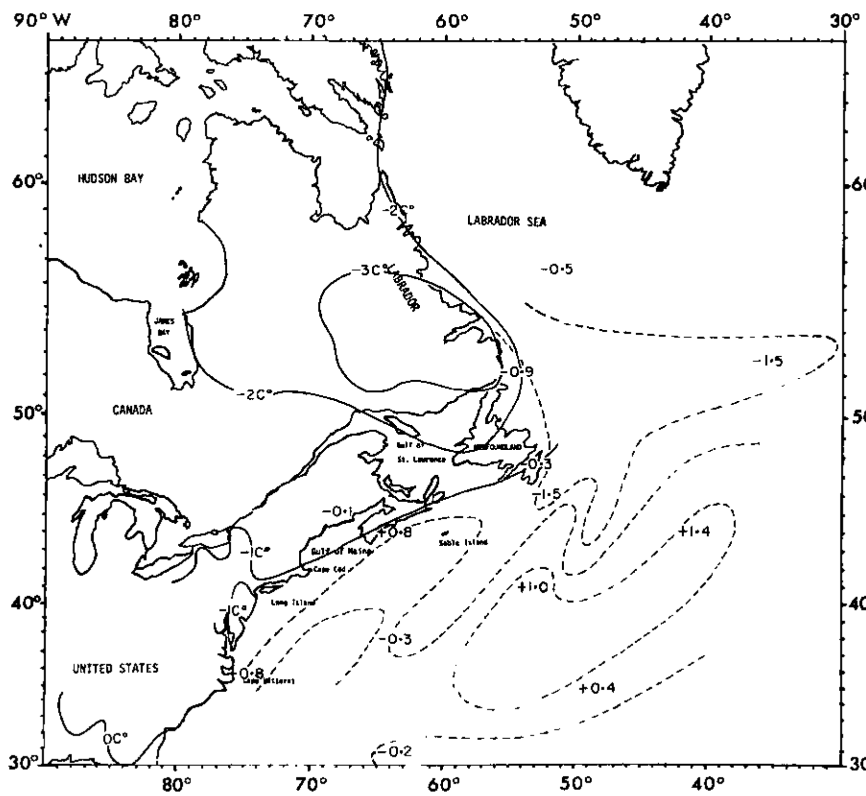

Fig. 3. Departures from normal of air and sea surface temperatures for spring 1972.

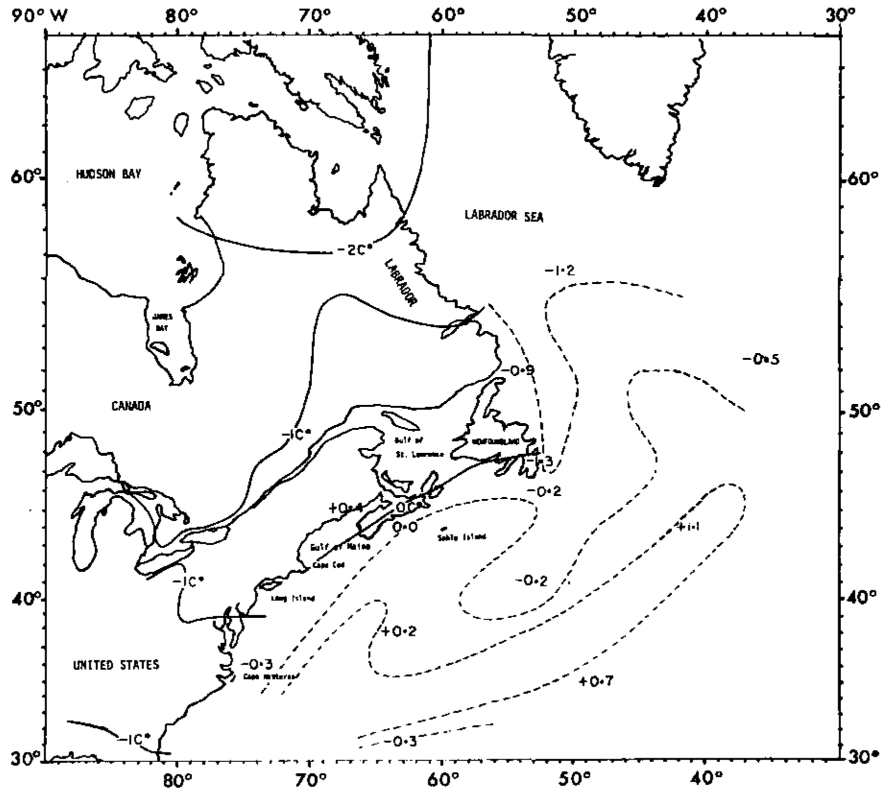

Fig. 4. Departures from normal of air and sea surface temperatures for summer 1972.

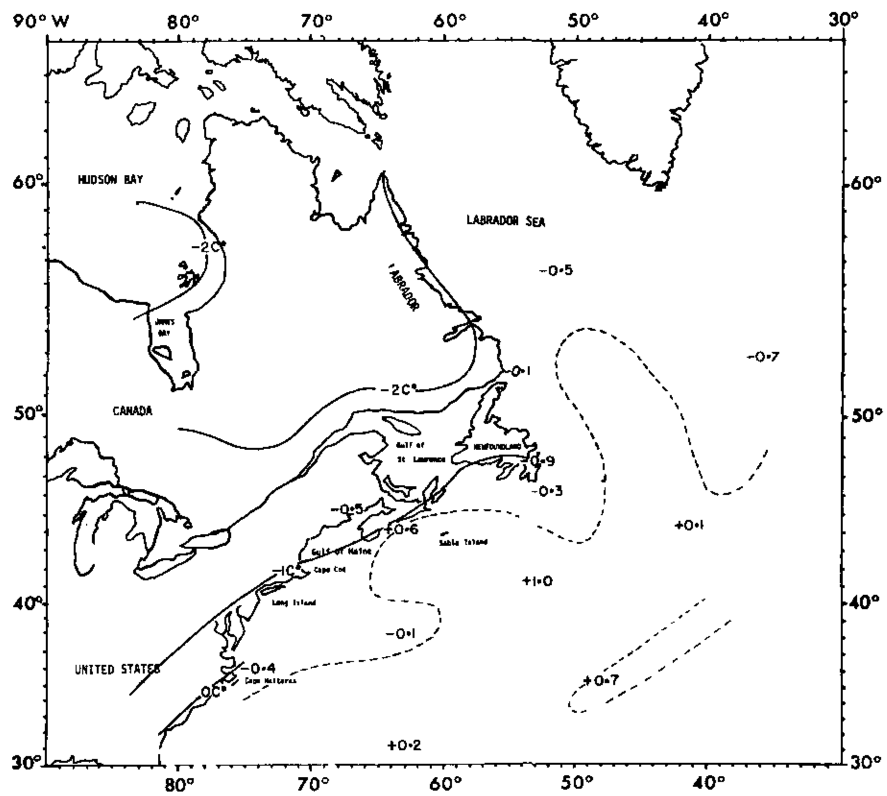

Fig. 5. Departures from normal of air and sea surface temperatures for autumn 1972.

and were influenced by abnormally warm air temperatures.

The impact of the flow of colder waters in the Grand Banks region appeared to be greatest in the east in the spring and in the south in the summer.

The elevation or lowering of sea surface temperatures is caused by the amount of surface warming or cooling and by the influence of waters from outside the area. An additional influence is the time-lag for waters to flow from one area to another. The warmer waters that appeared in the winter off Cape Hatteras were south of the Grand Banks approximately four months later and, additionally, some two months later east of the Grand Banks. These time periods are in good agreement with time values based on average current speeds of 16 miles per day (30 km/day) and 9 miles per day (17 km/day) respectively. (Anon., 1953)

The development of a summer-warmed surface layer tends to reflect the amount of warming through the atmosphere. The departures from normal for the summer season (Fig. 4) show a close relationship between those for the seas and those for the atmosphere. A notable departure from this scheme was south of the Grand Banks where the dynamics of the system maintained colder temperatures through the large amount of Labrador current water.

The relaxation of the cooling situations in the autumn (Fig. 5) over the land appeared to be reflected in the return to near normal sea surface temperatures. In the Cape Hatteras region the waters appeared to reflect the southward flow of cooler coastal water into that area. South of the Grand Banks, the greater influx of cold Labrador water appears to have drawn warmer water into the region as evidenced by the positive departures from normal at Position 8.

It is seen that a few selected points scattered throughout the ocean do not provide, by themselves, a clear description of the events that took place. The values obtained for a given position are the resultant of the influence of local events, far distant events and the effect of the ebbing and flooding of ocean streams. To gain a better understanding of the causes of departures from normal, a broader view of the events that took place is required.

A more comprehensive view can be obtained from the distribution of selected isotherms for the periods of maximum and minimum sea surface temperatures. When compared with normals for these periods, the relative changes that took place are more readily discernable. Figures 6 and 7 show the distributions of sea surface temperature for the periods 14-20 March, 1972 and 15-21 August, 1972 respectively, as well as the distributions of the normal monthly mean sea surface temperature. (Anon., 1967)

In general, the Gulf Stream waters were warmer and the northern waters were colder than normal, with the waters between these two near normal. The most noteworthy feature shown in the two diagrams is the southward extension of the Labrador Current. The interpretation placed on the relative shifts in the sea surface temperature patterns is that during 1972 both the Gulf Stream and the Labrador Current experienced greater circulations. Depending upon where we chose to measure the sea surface temperature, some drastic changes could be observed.

The below-normal temperatures had a significant effect on the ice conditions off the eastern shores of Canada. During the cool summer, the carry-over of old ice in Baffin Bay and Fox Basin was the greatest since such records were first kept in 1950. With the extraordinary cold December along the Labrador coast, the buildup of ice north of Newfoundland was extensive at the end of the year. The extensive cover of sea ice undoubtedly plays a very significant role in the protection of icebergs from wave erosion in their southbound drift along the Canadian coast, such that about 10 times the normal number of icebergs were reported by early July. The coverage of sea ice and icebergs in 1972 is shown in Fig. 8.

As was seen in Fig.2-5, the seasonal departures from normal of sea surface temperature were not negative at all positions in 1972. Based on average temperatures for the period 1962-73 for oceanic positions and the period 1962-72 for the two coastal stations, six selected curves of seasonal departures from normal are depicted in Fig. 9. It is readily discernable that these curves do not particularly resemble one another. It is obvious that in 1972 sea surface temperatures were much below normal at all these positions except at St. Andrews, New Brunswick, Canada, and Position 3 in the Gulf Stream. It is also worthy of note that:

a) 1973 was below normal in the Grand Banks region;

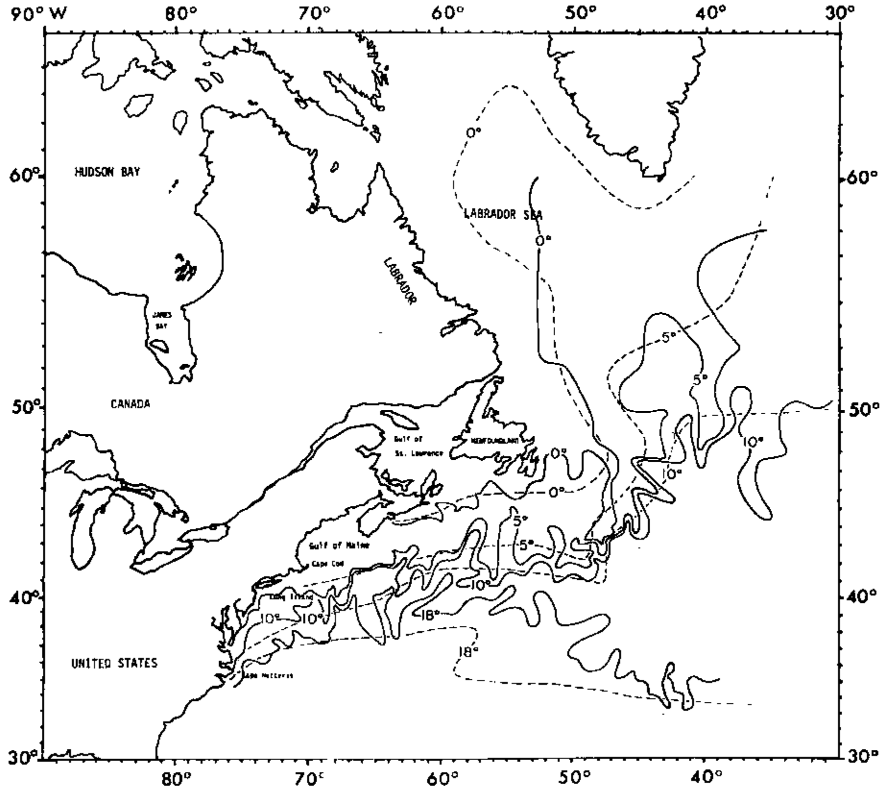

Fig. 6. Distributions of sea surface temperatures - March.

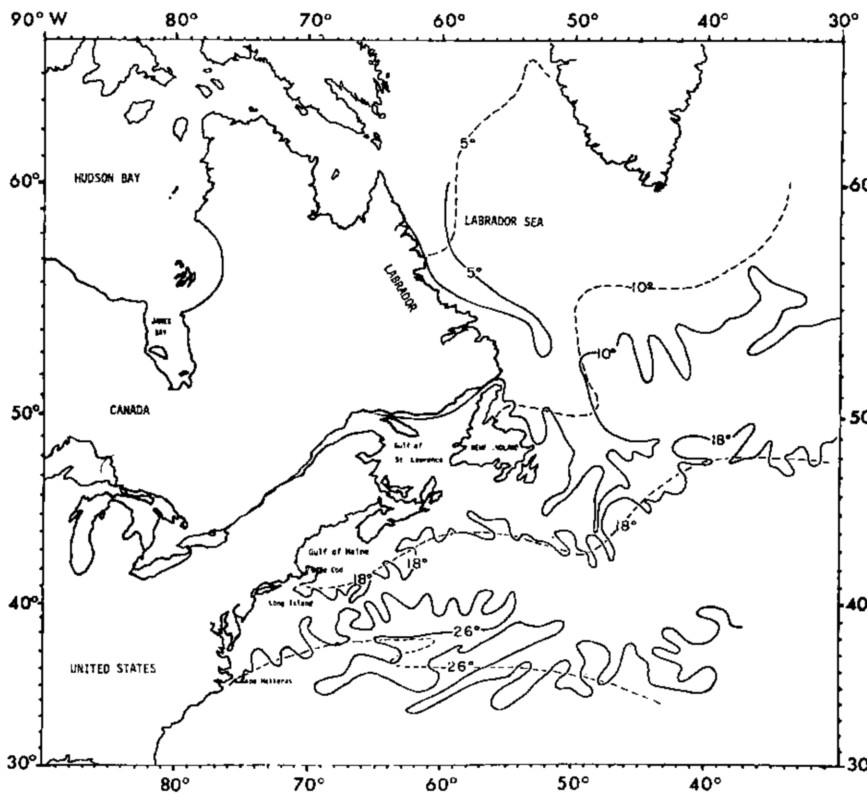

Fig. 7. Distributions of sea surface temperatures - August.

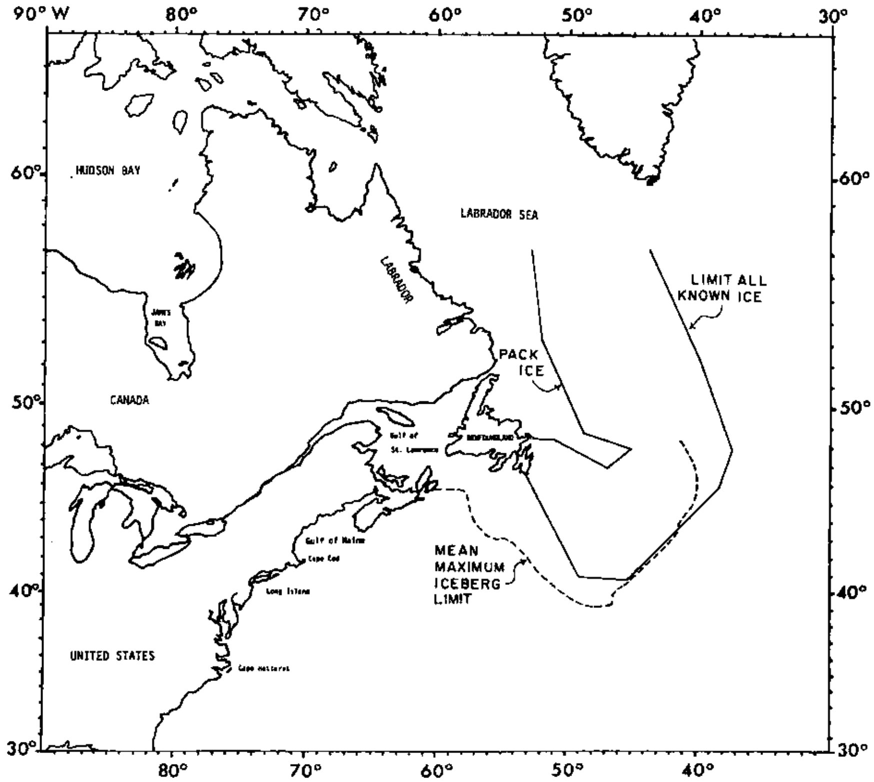

Fig. 8. Limits of sea ice and icebergs - 12 May 1972. (maximum southward extension).

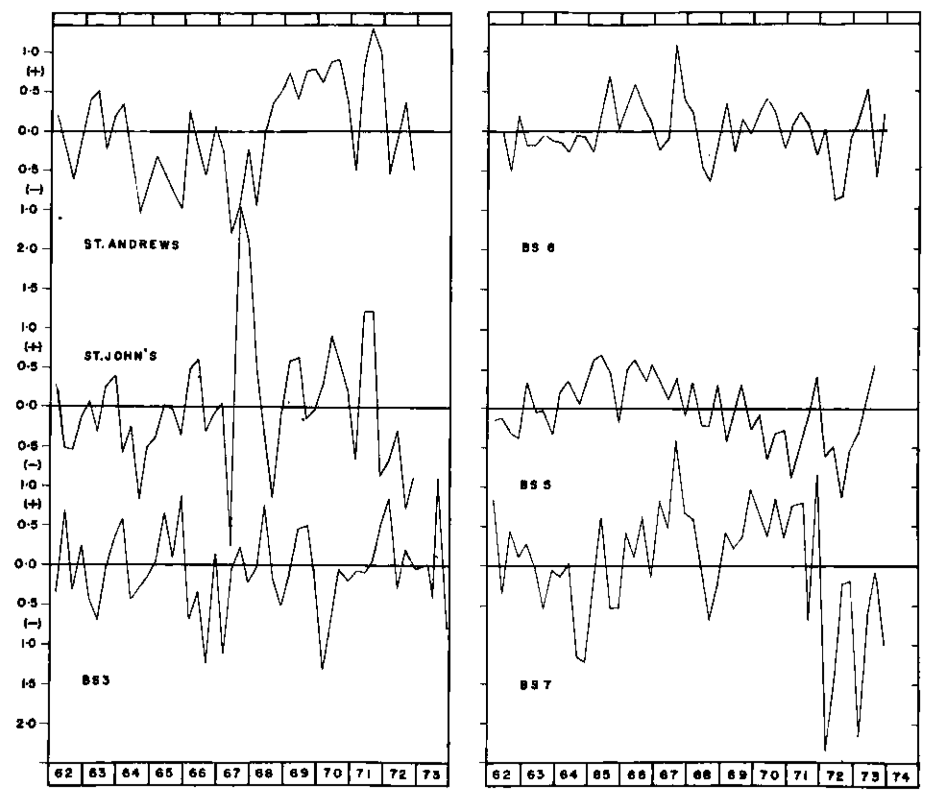

Fig. 9. Seasonal departures from normal at selected stations for the period 1962-73.

b) other cold years were 1964 and 1968 at Position 7, St. Andrews, St. John's and only 1968 at Position 6, whereas Positions 3 and 5 in the open ocean were generally near normal or slightly above normal;

c) the warm year 1967 showed a departure from normal of +2.62°C in the summer at St. John's (and a spring departure from normal of -1.8°C). This was also the warmest during the period at Position 6 and 7. However, Position 5 in the Labrador Sea was only marginally above normal and St. Andrews and Position 3 in the Gulf Stream were much below normal.

These plots of seasonal departures from normal indicate that both local and large scale influences, that go into determining the nature of the sea surface temperature, may be followed as the effects of warming or cooling by the waters as they move from one area to another.

Yearly Departures from Normal

There is a strong tendency in discussing a diagram such as Fig. 9 to look at the peaks and valleys and term the year in which they occurred as either warm or cold years. Frequently the situation was such that a particular season was much above or below normal. An excellent example of this occurred in 1967 at St. John's, where the seasonal departure from normal in the spring was -1.8°C and in the summer +2.6°C, both of which were the largest during the period 1962-72. If one were to look at the departures of annual means from normal over this period, a typical saw-toothed curve for a dozen points would be observed. A comparison of these curves for the eleven oceanic stations showed, for the interval 1962-70, a generally undecipherable criss-cross of lines. However, from 1970 to 1973, and particularly in the last 3 years, there is a clear separation of the curves into two groups; those with maxima, and those with a minima in 1972. Those stations which held minima in 1972 were Stations 5, 6, 7 and 9. These are the most northerly of the stations and closest to the centre of sub-normal air temperatures. The intermediate Stations 2, 8 and 10 had their largest positive departures (Stations 8 and 10) or the second largest (Station 2) over the period.

In the south, Stations 1 and 11 showed the same characteristics as Stations 8 and 10, whereas at Stations 3 and 4 in the Gulf Stream and Sargasso Sea the relationship is not as distinct.

As a result of these clear relationships between stations for a short period at least, it was considered that it might be instructive to construct regression lines based on the annual departures from normal for each pair of stations.

The results of the correlation of the yearly departures from normal of the sea surface temperatures over the period 1962-73 for Station 7 (representative of the Grand Banks, with which this Symposium is primarily concerned) and surrounding stations are shown in Fig. 10, although as an example of this kind of study, the selection of Station 7 is a poor one.

Perhaps of greater interest is the fact that there appear to be a number of double correlations. In the best examples of this effect, one group of data will have a positive correlation while a second group will have a negative correlation, with the two regression curves normal to each other.

There are a number of cases where certain years fall well away from any curve. In the content of annual departures from normal those years would be considered unusual, indeed.

However, when consideration is given to the fact that the processes of winter chilling and summer warming are entirely different and that they are generally accompanied by different wind systems both in strength and direction, then a more appropriate way in which to view the relationships between stations is on a seasonal basis.

While the work of producing these seasonal correlations has not been completed, there are clear indications that seasonal conditions are very important in determining the nature of events over the year. At some pairs of stations the relationship may be negative at one season and positive at another season. These seasonal departures produce a clearer idea of what took place in the relationships between stations so that what appeared to be an anomalous situation with respect to annual departures is merely the occurrence of an event further along a regression line in a particular season.

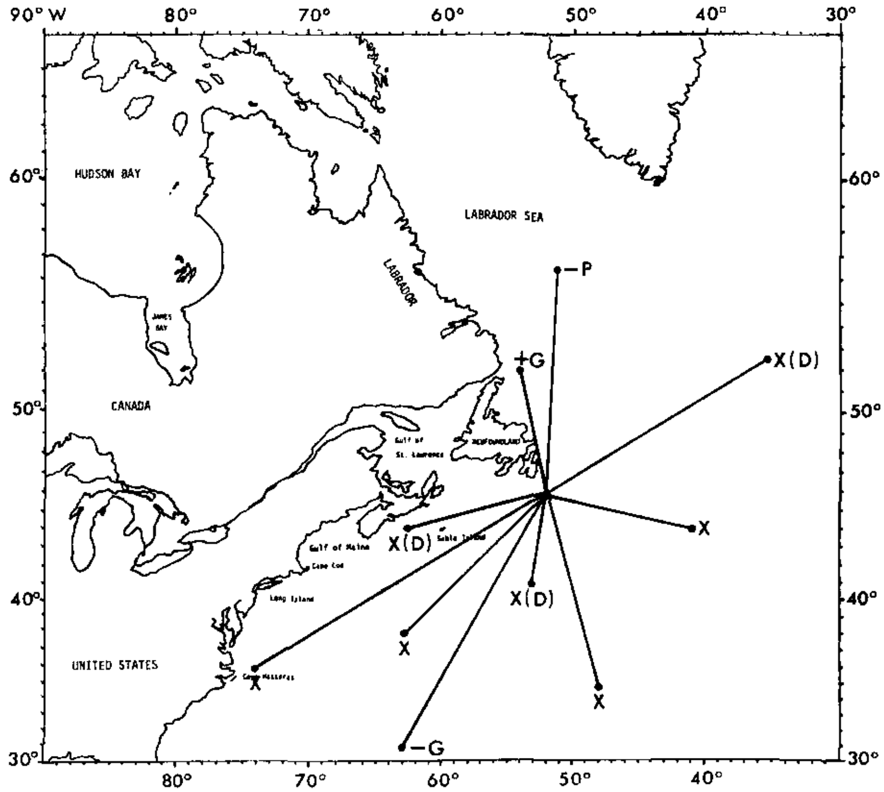

Fig. 10. Correlations of the yearly departures from normal of sea surface temperatures over the period 1962-73 (P-Poor, F-Fair, G-Good, E-Excellent, D-Double, (D)-Possible Double, X-None).

In considering the evidence currently available, and certainly more needs to be looked at, it does not appear that 1972 was unusual in that it did not fit into any recognizable pattern of events, but was merely a cold year in certain areas.

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Comparison of Temperatures in July-August Hydrographic Sections of the Eastern Newfoundland Area in 1972 and 1973 with those from 1951 to 1971

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INTRODUCTION

For most years since 1951, six hydrographic sections have been taken by the St. John's Station in July-August across the Labrador Current, Continental Shelf and banks of the eastern Newfoundland area from southern Labrador to the southern Grand Bank. Because of lack of research vessels, only the St. John's to Flemish Cap section was taken in the years 1966-68. For each of these sections, averages of corrected temperatures at certain depth levels have been calculated, and the highest and lowest temperatures of the period 1951-71 recorded for each depth level of the St. John's-Flemish Cap section, and of the composite total of 1951-65, 1969-71 (usually called 1951-71) for each of the other sections.

The following stations were not completed in some of these years:

Section A, Seal Island section: Station 57 was not taken in 1951-55 and 1961 and at depths of 600-100 m not before 1960;
Section B, Cape Bonavista section: Station 49 was not taken in 1951, Station 50 in 1954 and at 600-1,000 m not before 1960;
Section C, St. John's-Flemish Cap section: Station 42A was not taken before 1961 and Stations 42 and 42A were not taken in 1966;
Section D, St. John's-Southeast Shoal section: Station 33A and 33B were not taken in 1951 and 33A is omitted in shallow stations in Fig. 4 for lack of space. Station 33D was not taken before 1956. Station 33F was not taken before 1957 and at 600-1,000 m not before 1960;
Section E, Green Bank-Southeast Grand Bank at about 75 m. Station 26F was not taken before 1957 and at 600-1,000 m not before 1961;
Section F, St. Pierre Bank-southwestern Grand Bank slope at about 275 m. Station 18 was first occupied in 1952 and Stations 13, 15, 17 and 19 in 1953. Stations 10 and 13 were not taken in 1958.

The ranges and averages of monthly dates in 1951-71 when the various sections were occupied, using stations regularly occupied during the period (Station number in parentheses), were:

	Western station		Eastern station	
Section	Range	Average	Range	Average
A	29 July-10 Aug[a]	2 Aug (51)	30 July-9 Aug	3 Aug (56)
B	25 July-6 Aug	31 July (43)	23 July-7 Aug	30 July[b] (50)
C	20-29 July	25 July (27)	22 July-1 Aug	27 July (41)
D	8-21 Aug	16 Aug (27)	10-22 Aug	18 Aug (33)
E	13-26 Aug	21 Aug (20B)	11-24 Aug	19 Aug (26D)
F	12-25 Aug	21 Aug (16)[c]		

[a]Except for 1 year, 29 July-6 August.

[b]Stations not occupied in 1954 for which the date would have been 29 July.

[c]The only station occupied in all years of the period. Section F is worked on approximately the same dates as Section E by zigzagging between adjacent stations of the two sections.

The monthly dates in the legends of Fig. 1-6 for the averages, and highest and lowest temperatures, of the 1951-71 period are for the stations included in these averages etc.

For the temperatures taken near bottom where depths from year to year are irregular, for purposes of the average and highest and lowest temperatures of the 1951-71 period and 1972 and 1973 separately, temperatures have been estimated for the same depth at any one station, intermediate between the depth extremes. These near-bottom temperatures for 1972 and 1973 will therefore often differ slightly from those used elsewhere for the individual years where actual near-bottom temperatures and depths are used.

In the early years, 1951-58, temperatures were taken at 25 m but not at 10, 20, 30 m, the depths used after 1958. In order to compare with the earlier years, for years after 1958 a 25 m temperature has been estimated, usually from bathythermograph records, and used for averages and highest and lowest temperatures. This is another point of difference between the sections for 1972 and 1973 presented here and those used when presenting the yearly temperatures and salinities for these sections.

In the sections, apart from the surface temperatures, the position of the decimal point in an inserted temperature indicates its level and position unless an indicator line is used to denote the actual position.

In difficult parts of sections for 1972 and 1973, bathythermograph records taken between the regular stations were used to improve the location of the isotherms but not for the actual temperature records. Note that the 1972-73 sections have differing depth proportions than the average, and highest and lowest, temperature records. This was due to the combination of sections prepared for other purposes and which differed in this regard.

For many years, the author (Templeman, 1955-73) produced yearly summaries of the July-August temperature sections described in this paper and also of the related salinity sections, and of temperature variations throughout the year, and between years, at Station 27 off Cape Spear near St. John's. This station is the shoreward station of Fig. 3 and 4. The unusually low temperatures in the Labrador Current in 1972 were noted by Templeman (1973) and by Burmakin (1973).

Judging from the Flemish Cap section which was taken in these years (Templeman, 1967b, 1968, 1969), the general picture of July-August temperatures for the years 1966-68 when the other sections were not taken was as follows:

<u>1966</u>: Surface temperatures mostly the highest of the 1951-73 period; temperatures of the colder sector of the Labrador Current and in the deep offshore water generally above average but not the highest of the 1951-73 period.
<u>1967</u>: Surface temperatures above average. Temperatures of the colder sector of the Labrador Current water close to the lowest of the 1951-71 period but not as low as in 1972 or 1973. Temperatures above average in the deep water of Flemish Channel and close to average in the deep water seaward of Flemish Cap.
<u>1968</u>: Surface temperatures generally the lowest of the 1951-73 period. Temperatures mainly a little above average in the colder sector of the Labrador Current water and also mainly above average in the offshore deep water in Flemish Channel and seaward of Flemish Cap, related to the West Greenland Current.

Sections Across the Labrador Current in July-August 1951-73

<u>Section A, Seal Island - Hamilton Inlet Bank</u>

<u>1972</u>. In this southern Labrador section (Fig. 1), surface temperatures in 1972 (Fig. 1D) were below average (Fig. 1C) at all stations, and at the two most seaward stations below the lowest previously encountered (Fig. 1B). At 25 m, temperatures in 1972 were well below average at all stations except 53A and at the three eastern stations and especially the most seaward two, were well below any previously taken. At 50 m, temperatures were well below average at all stations and at seven of nine stations, and especially at the outer two, below any previously found. At 75 m, temperatures at all stations, and especially the outer three, were well below average, and at one station equal to, and at the remaining eight stations lower than, any taken previously. At 100 m at all stations, temperatures were lower, and at Stations 55A and especially 56 considerably lower, than any found previously. At 150 m, all temperatures except that at 53A were lower, and at Station 55A and especially Station 56 much lower, than any taken previously. At and near 200 m, the temperature at Station 53 was similar to the lowest

previous temperature; near bottom temperatures above Hamilton Inlet Bank at Stations 53A and 54 were above the average, and temperatures at the three Stations 55-56 were considerably lower than any previously encountered. Temperatures at 250 m, and near bottom in the channel at Station 53, were lower than any previously found. Seaward of Hamilton Inlet Bank at Stations 55-56, temperatures at 250 m were well below any previously found, especially at Stations 55 and 55A, also the temperatures at 300 m at Station 55 and 55A.

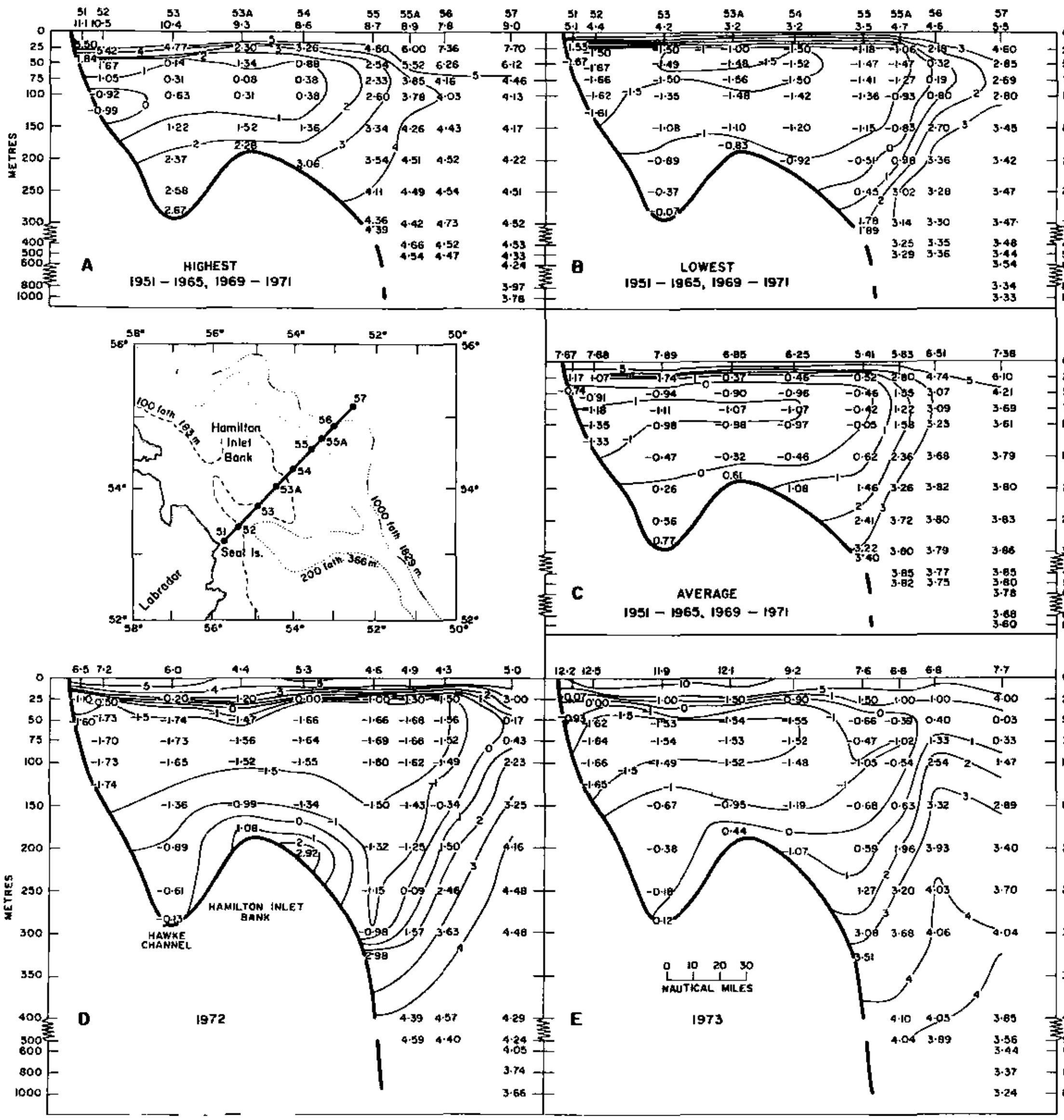

Fig. 1. Temperatures (°C) in Section A, Seal Island-Hamilton Inlet Bank: A, highest; B, lowest; C, average; for the period 1951-65, 69-71, 29 July - 10 August, mean dates 2-3 August; and D and E for 1-2 August 1972 and 31 July - 1 August 1973.

In the seaward stations where the deep water was related to the West Greenland Current, temperatures at the most seaward station at all depths from 200 m and greater were above average and almost as high as any previously encountered (Fig. 1A), and similarly at 400 and 500 m at Stations 55A and 56 where two of the four temperatures were slightly higher than any previously found.

1973. In the Seal Island section in 1973 (Fig. 1E), surface temperatures were above average at all stations and at the coastward 5 stations were higher than any previously encountered. At 25 m, temperatures were below average in seven of nine stations and at the two outer stations were below the lowest of the 1951-71 period, but not as low as in

1972. At 50 m, temperatures at all stations were below average, at Stations 53-54 and 57 below the lowest temperatures of the 1951-71 period, and at Stations 53A and 57 temperatures were the lowest of the 1951-73 period. At 75 m, all temperatures were below the average, at three of the eight stations below the lowest of the 1951-71 period, and at the most seaward station the temperature was the lowest of the 1951-73 period. At 100 m, temperatures were all below the average for 1951-71 and at the four coastward Stations 52-54, and the most seaward Station (57) below the lowest of the 1951-71 period. At Station 53A, the temperature equalled the lowest, and at the most seaward Station (57) was the lowest, of the 1951-73 period. At and near 150 m, temperatures were all below the 1951-71 averages, at Stations 52 and 57 lower than any of the 1951-71 period and at Station 57 the 1973 temperature was the lowest of the 1951-73 period. At and near 200 m, temperatures were below average (sometimes only slightly below) at all stations except Station 56 but only the temperature at Station 57 was slightly below the lowest of the 1951-71 period. Except at Station 57, near bottom, and above Hamilton Inlet Bank at Stations 53A and 54, where the temperatures were lower, all temperatures were higher than those of 1972. Temperatures at 250 m, and near bottom in Hawke Channel, were below average except at Station 56, but all were higher than the lowest of the 1951-71 period and all (except at Station 57 where the temperature was lower) higher than those of 1972.

Seaward, at Stations 55-57, temperatures at 300 m were below average, but above the lowest of the 1951-72 period, at Stations 55 and 55A and above average, but below the highest of this period, at the two seaward stations. At 400 and 500 m, temperatures (except at Station 57) were above average but below the highest of the 1951-72 period. At Station 57, the most seaward, temperatures at 400 m were equal to the average, at 500-1,000 m below the average of the 1951-71 period and close to the lowest, and at 600 and 1,000 m slightly the lowest of the 1951-72 period.

Section B, off Cape Bonavista

1972. In the Cape Bonavista section in 1972 (Fig. 2D), surface temperatures were all below the averages of the 1951-65, 1969-71 (subsequently called 1951-71) period (Fig. 2C), and at Station 50, below the lowest of this period (Fig. 2B). At 25 m, temperatures were all below average and at Stations 48 and 50 were below the lowest for the 1951-71 period. At 50 m, all temperatures were below the 1951-71 averages and at Stations 46 and 49 were the lowest of the 1951-72 period. At 75 m, all temperatures were below average and at four of seven stations were the lowest of the 1951-72 period. At 100 m, all temperatures were below average and at three of seven stations were the lowest of the 1951-72 period. At 150 m, all temperatures were below average and at two of six stations were the lowest in 1951-72. At 200 m, all temperatures, except at the most seaward Station (50), were below average and one of six was the lowest of the 1951-72 period. At 250 m, temperatures at four of six stations were below average but none were the lowest in 1951-72. At 300 m, temperatures were below average at three of six stations but none were the lowest of the 1951-72 period. In the most seaward Station (50) temperatures were below average down to 150 m, above average from 200 to 600 m [but only at 300 m was the temperature the highest of the 1951-72 period (Fig. 2A)] and slightly below average at 800 and 1,000 m.

1973. In this Cape Bonavista section in 1973 (Fig. 2E), surface temperatures were above average in six of eight stations but none were the highest or lowest of the 1951-73 period. At 25 m, temperatures were below average in six of eight stations but none were below the lowest of 1951-71. At 50 m, all temperatures were below the averages of 1951-71, three of eight were below the lowest of the 1951-71 period and two of these were the lowest of the 1951-73 period. At 75 m, all temperatures were below the averages of the 1951-71 period, five of seven were below the lowest of this period and two of these the lowest of the 1951-73 period. At 100 m, temperatures were all below the averages of the 1951-71 period, at three of seven stations lower than in the 1951-71 period and at two of these the lowest of the 1951-73 period. At 150 m, temperatures were all below average, at three of six stations below the lowest of the 1951-71 period and at two of these the lowest of the 1951-73 period. At 200 m, at all stations except the most seaward, temperatures were below average, and at two of six stations were the lowest of the 1951-73 period. At 200 m, all temperatures except that at the most seaward station were below average and two of six were the lowest of the 1951-73 period. At 250 m, temperatures in the three coastward stations were lower than the 1951-71 averages and at the most coastward station was the lowest temperature of the 1951-73 period. At 300 m, temperatures at four of the six stations were below average and at the most westward was the lowest temperature of the 1951-73 period. In the deep water below 300 m at the most seaward Station (50), temperatures from 400 to 1,000 m were all below the averages for 1951-71 and that at 600 m was the lowest of the 1951-73 period.

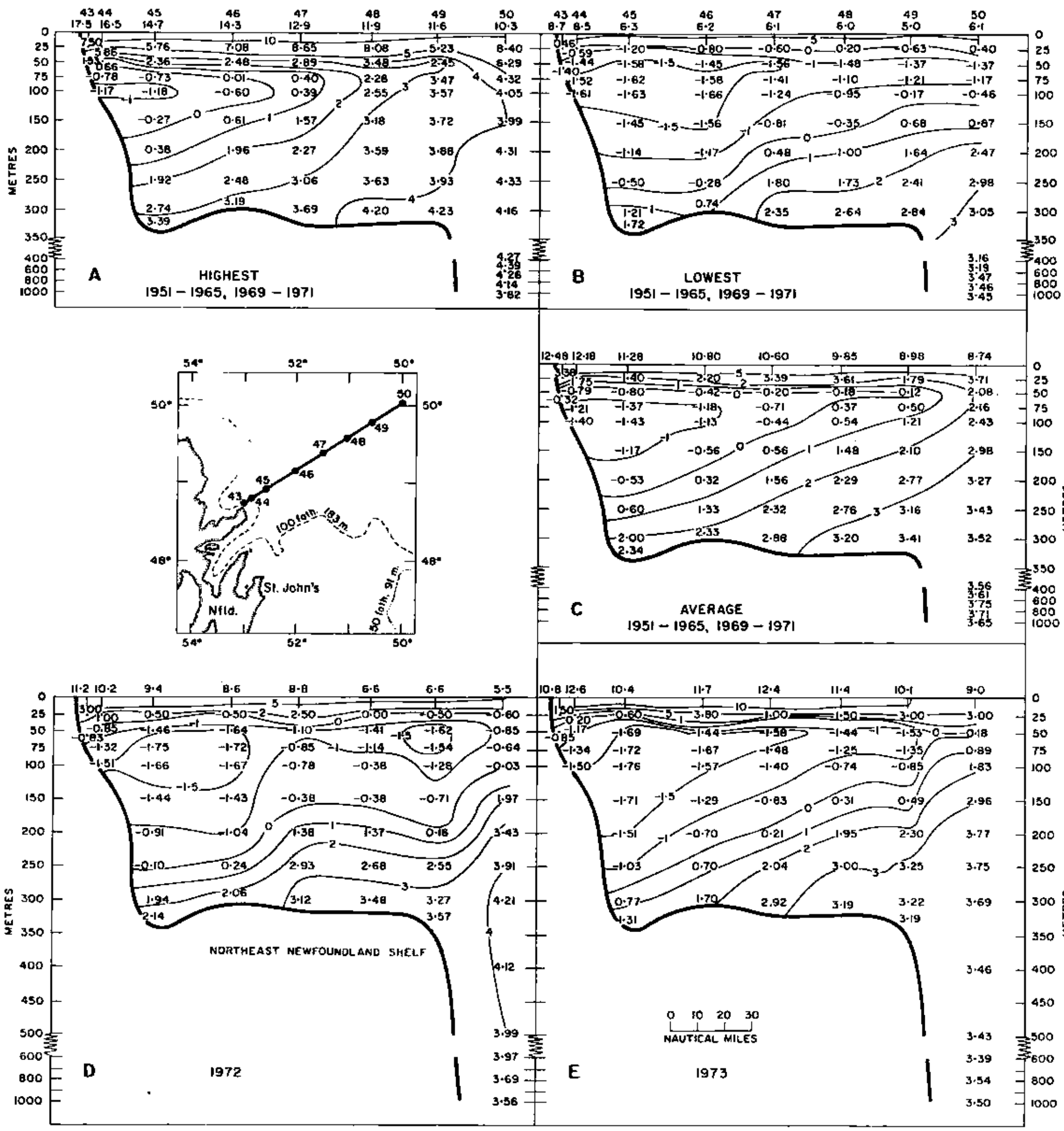

Fig. 2. Temperatures (°C) in Section B, off Cape Bonavista: A. highest; B, lowest; and C, average; for the period 1951-65, 1969-71, 23 July - 7 August, mean dates 30-31 July; and D and E, for 30-31 July 1972 and 29-30 July 1973.

Section C, St. John's-Flemish Cap

1972. In the St. John's to Flemish Cap section in 1972 (Fig. 3D), surface temperatures were below average (Fig. 3C) at most stations but were well above the lowest (Fig. 3B) of the 1951-71 period. At 25 m, ten of thirteen temperatures were below the averages of the 1951-71 period and one was the lowest of the 1951-72 period. At 50 m, all temperatures were below the averages for 1951-71 and at three stations were the lowest of the 1951-72 period. At 75 m, temperatures at all stations, except the most seaward (42A), were below the averages and at six of thirteen stations were below and at one station the temperature was equal to the lowest of the 1951-71 period. At 100 m, all temperatures except that at Station 42A, the most seaward, were below average and at six of eleven stations were below the lowest of the 1951-71 period. At and near 150 m, temperatures at eight of ten stations were below average and also the lowest of the 1951-72 period. At and near 200 m, temperatures at four of six stations were below average and also the lowest of the 1951-72 period. At 250 m, temperatures at three of five stations were below average and at two of these were the lowest of the 1951-72 period. At 300 m and deeper in the Flemish Channel, three of eleven temperatures were below average but none was the lowest of the 1951-72 period. Of the above-average temperatures, four at Station 39 from 300 to 600 m were the highest of the 1951-72 period. In the deep water seaward of Flemish Cap at 300 m and deeper, three of nine temperatures were below the 1951-71 averages, one equal to the average and one was the lowest of the 1951-72 period.

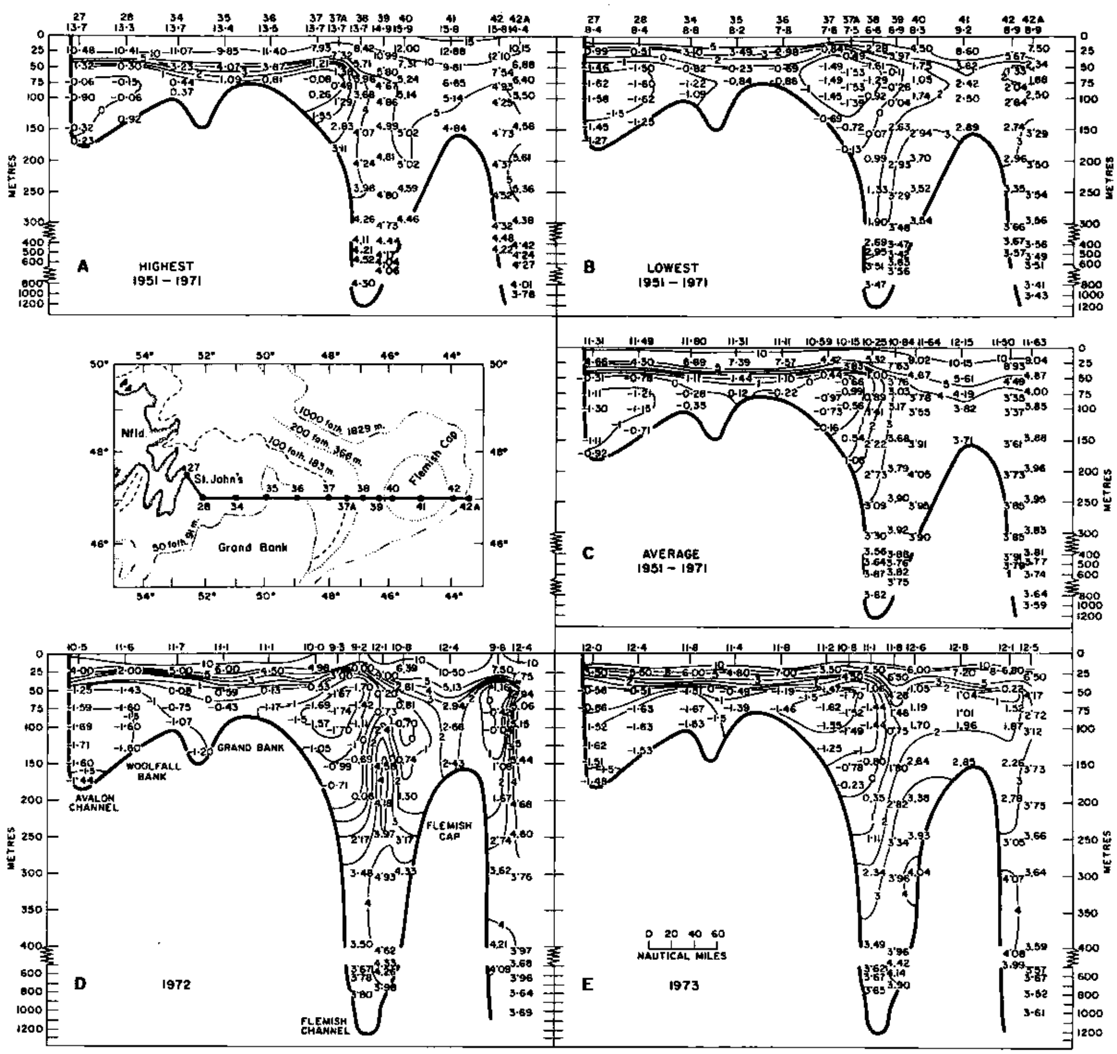

Fig. 3. Temperatures (°C) in Section C, St. John's-Flemish Cap: A, highest; B, lowest; and C, average; for the period 1951-71, 20 July - 1 August, mean dates 25-27 July; and D and E for 26-28 July 1972 and 25-27 July 1973.

1973. In the St. John's to Flemish Cap section 1973 (Fig. 3E), surface temperatures were above the averages for the 1951-71 period except at one station where they were equal, but all were below the highest of the period (Fig. 3E). At 25 m, temperatures were below average at eleven of thirteen stations and at two of the three most seaward stations were the lowest of the 1951-73 period. At 50 m, temperatures were below average at eleven of thirteen stations, at seven were below the lowest of the 1951-71 period and at six of these were the lowest of the 1951-73 period. At 75 m, temperatures were below average in twelve of thirteen stations, at eight were below the lowest of the 1951-71 period and at six of these were the lowest of the 1951-73 period. At 100 m, temperatures at all eleven stations were below average, at eight were lower than the lowest of the 1951-71 period and at four of these were the lowest of the 1951-73 period. At and near 150 m, temperatures were below average at all ten stations, at nine (all except the most seaward station) were below the lowest of the 1951-71 period and at three of these were the lowest of the 1951-73 period. At and near 200 m, temperatures were below average at all six stations, at five (all except the most seaward station) were below the lowest of the 1951-71 period and one of these was the lowest of the 1951-73 period. At 250 m, temperatures were below average at all five stations, at two were below the lowest of the 1951-71 period and at one of these was the lowest of the 1951-73 period. In depths of 300-800 m in Flemish Channel, five of eleven temperatures (all on the Grand Bank side) were below average and all were below those of 1972 but none were as low as the lowest for the 1951-71 period. In depths of 300-1,000 m seaward of Flemish Cap, five of nine temperatures were below average and eight were below those of 1972, but none was as low as the lowest of the 1951-71 period.

Section D, St. John's - Southeast Shoal

In Section D (Fig. 4), the hydrographic sections related to averages, highest and lowest temperatures of the 1951-71 period (Fig. 4A,B,C,) extend to Station 33F. When cold water extended farther seaward, additional seaward stations were occupied as in Fig. 4D and especially 4E. These additional stations are not considered in the detailed comparisons but are used for the summary.

1972. In Section D, St. John's to the Southeast Shoal of the Grand Bank, surface temperatures in 1972 were below the 1951-65, 1969-71 (subsequently called 1951-71) averages at all stations except 32 and 33 and the temperature at Station 33F was the lowest of the 1951-72 period but the two higher-than-average temperatures were not the highest of the period. At 25 m, eight temperatures were below and two above the averages of the 1951-71 period and three of these below-average temperatures were the lowest of the 1951-72 period. The two above-average temperartures were not the highest of the period. At and near 50 m, eight temperatures were lower and two higher than the 1951-71 averages and four of these below-average temperatures were the lowest of the 1951-72 period. The above-average temperatures were not the highest of the period. At and near 75 m, all temperatures except that at Station 33F were below the averages of the 1951-71 period and the temperature at Station 28 was the lowest of the 1951-72 period. The above-average temperature was not the highest of the period. In the Avalon Channel, temperatures at 100 m and deeper were all below average and all the lowest of the 1951-72 period. Seaward of the Southeast Shoal at 100 and 150 m, all temperatures except those at Station 33F were below the averages for the 1951-71 period and one was slightly the lowest of the 1951-72 period. Temperatures at Station 33F were not the highest of the period. In this seaward area at 200-300 m, eight temperatures were below and five above the averages for the 1951-71 period and three at Station 33 were the lowest of the 1951-72 period. None of the above-average temperatures was the highest for the period. At 400-500 m, three temperatures were below and five above the averages for the 1951-71 period but none was the lowest or the highest of the period.

1973. In 1973 in Section D (Fig. 4E), all surface temperatures were below the averages for the 1951-71 period and at Station 33F slightly below the lowest of the 1951-71 period but not the lowest of the 1951-73 period. At 25 m, five of the six seaward temperatures (stations seaward to 33F only, considered here) were below average and that at Station 31 were below the lowest for the 1951-71 period, but was not the lowest for the 1951-73 period. None of the above-average temperatures were above the highest of the 1951-71 period. At and near 50 m, eight of the ten temperatures were below average, five of these were below the lowest temperatures for 1951-71 and 3 (at Stations 29-31) were the lowest of the 1951-73 period. The two above-average temperatures were well below the highest for the period. At 75 m, temperatures at all stations were below average and at four Stations (28, 29, 30, 33F) were below the lowest for the 1951-71 period. Temperatures at the latter three stations were the lowest of the 1951-73 period and at Station 28 only 0.01°C above the lowest for this period. In the Avalon Channel at and below 100 m, temperatures were all below the lowest of the 1951-71 period and all except that for Station 28 at 100 m the lowest of the 1951-73 period. Seaward of the Grand Bank at Stations 33-33F at 100 and 150 m, temperatures at all stations were below the 1951-71 averages and at Station 33F were the lowest of the 1951-73 period. Also, seaward at the same stations from 200 to 300 m, nine temperatures were below and four above the 1951-71 averages and one temperature at Station 33F (300 m) was the lowest for the 1951-73 period. None of the above average temperatures were the highest for the period. At 400 and 500 m, three temperatures were lower and five higher than the averages for the 1951-71 period but none was the lowest or highest for the period.

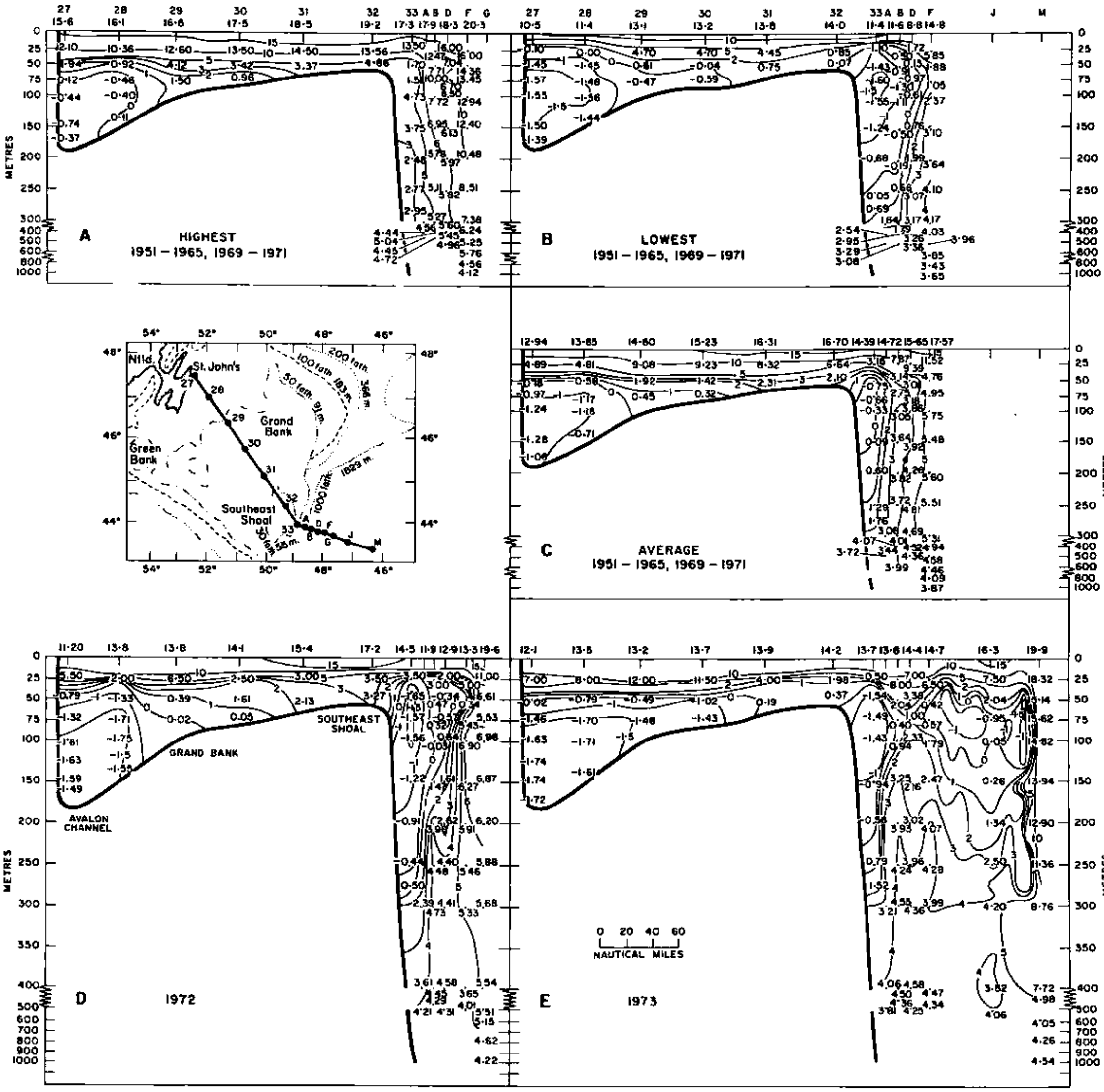

Fig. 4. Temperatures in Section D, St. John's - Southeast slope Grand Bank: A, highest; B, lowest; and C, average; for the period 1951-65, 1969-71, 8-21 August, mean dates 16-18 August; and D and E, for 19-20 August 1972 and 15-16 August 1973. (Temperatures for Station 33A are omitted for lack of space except at the greater depths.)

Section E, Green Bank-Southeast Grand Bank

For the detailed comparison of temperatures in 1972 and 1973 with averages, lowest and highest temperatures of previous years, Section E (Fig. 5), only Stations 20B to 26F can be used. In 1972 and 1973 additional stations to the east of Station 26F were added.

1972. In Section E, from Green Bank across the southwestern slope of the Grand Bank at about 75 m to the slope of southeastern Grand Bank, surface temperatures in 1972 were all, except three, above the 1951-65, 1969-71 (subsequently called 1951-71) averages. None of the above-average temperatures were the highest and none of the below-average temperatures the lowest of the 1951-72 period. At 25 m, eight temperatures, including the four most seaward at Stations 26A-26F, were below and 5 were above the averages for 1951-71. Only one of the below-average temperatures (at Station 22) was the lowest of the 1951-72 period and none of the above-average temperatures were the highest of the period. At 50 m, all temperatures, except that at Station 26A, were below the averages of the 1951-71 period and five were the lowest of the 1951-72 period. The above-average temperature at Station 26A was not the highest for the period. At and near 75 m, all temperatures, except those at Stations 22, 23 and 26A, were below the averages for the 1951-71 period and at the western Stations 20B and 20A and the eastern Stations 26B and 26D were the lowest of the 1951-72 period. None of the above-average temperatures were the highest for the period. Temperatures in the Haddock Channel were the lowest of the 1951-72 period. On the eastern slope of the Grand Bank, temperatures at 100 and 150 m were all (except that at Station 26F at 150 m which was below average) the lowest of the 1951-72 period. On the eastern slope at 200-250 m, temperatures at Stations 26B and D were the lowest of the 1951-72 period and temperatures at Station 26F were above average, but not the highest of the period. At 300-500 m, two temperatures were lower and four higher than the averages for 1951-71. Those below the average were not the lowest of the 1951-72 period, but that at 26F at 400 m was the highest for the period.

1973. In Section E in 1973 (Fig. 5E), all surface temperatures, except those at Stations 26D and 26F, were below the 1951-71 averages and three were the lowest of the 1951-73 period. The two higher-than-average temperatures were not the highest of the period. At 25 m, six temperatures were lower and seven higher than the 1951-71 averages.

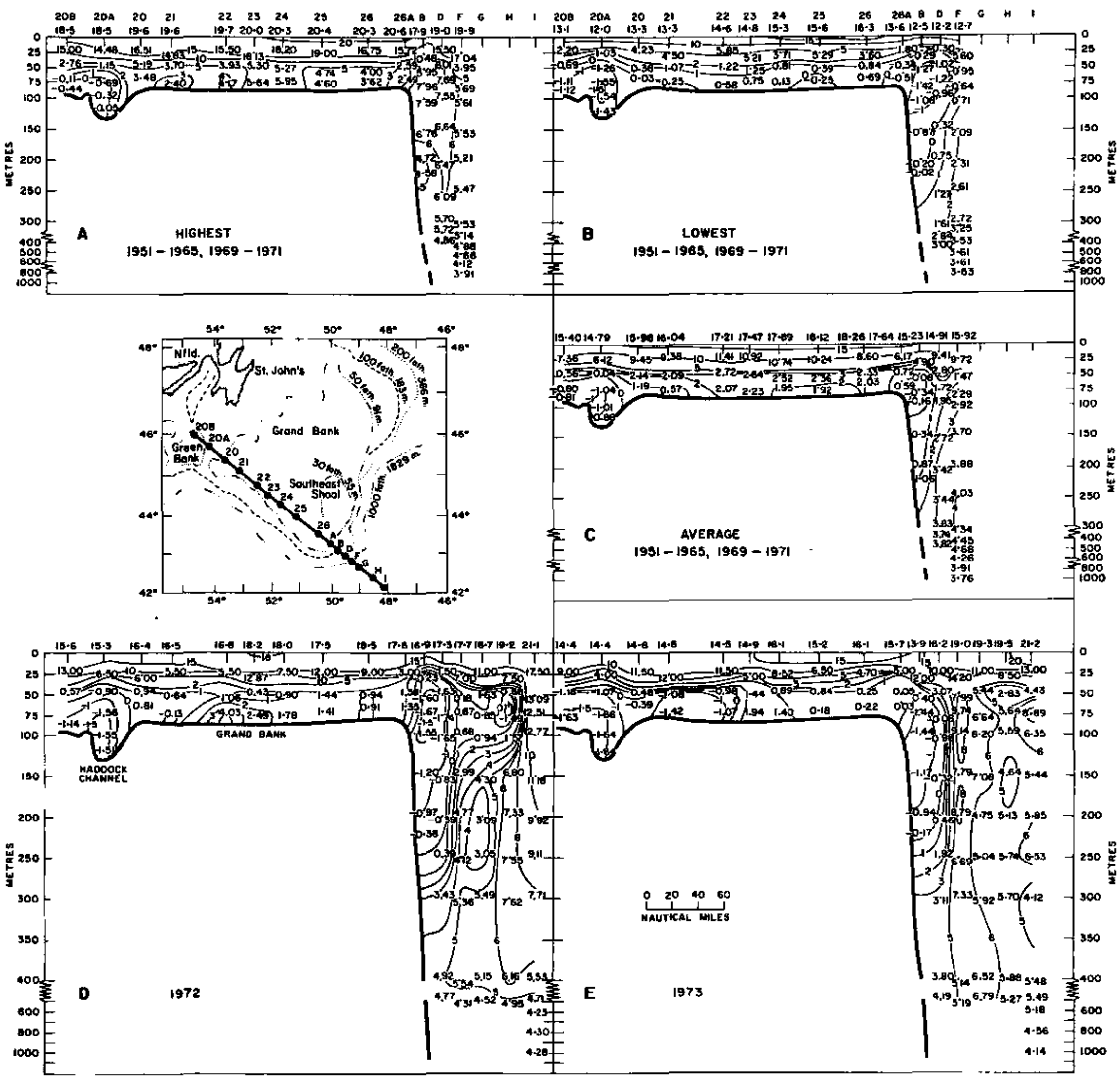

Fig. 5. Temperatures in Section E, Green Bank-Southeast Grand Bank: A highest; B, lowest; and C, average; for the period 1951-65, 1969-71, 11-26 August, mean dates 19-21 August; and D and E for 21-25 August 1972 and 18-21 August 1973.

One of the below-average temperatures was the lowest and one of the above-average temperatures the highest of the 1951-73 period. At 50 m, all except the three most seaward temperatures of the eastern slope (at Stations 26B-26F) were below the 1951-71 averages and four were the lowest of the 1951-73 period. The above-average temperature at Station 26F was the highest of the period. At and near 75 m, all temperatures except that at Station 26F were below the averages for 1951-71, at the five western Stations (20B-22) and at Stations 26 and 26B were below the lowest of the 1951-71 period and at all of these except at Station 26B were the lowest of the 1951-73 period. The above-average temperature at Station 26F was the highest of the 1951-73 period. In the Haddock Channel at Station 20A, temperatures were the lowest of the 1951-73 period. On the eastern slope of the Grand Bank at 100-200 m, temperatures at Stations 26B and 26D were below the lowest of the 1951-71 period but not as low as in 1972, and temperatures at Station 26F were the highest of the 1951-73 period. At 250-300 m, temperatures at Station 26D were below the averages for 1951-71 but not the lowest for the 1951-73 period, and at Station 26F, temperatures were the highest of the period. At 400-500 m, temperatures were above the averages of the 1951-71 period and at Station 26F the temperature at 500 m was the highest of the 1951-73 period.

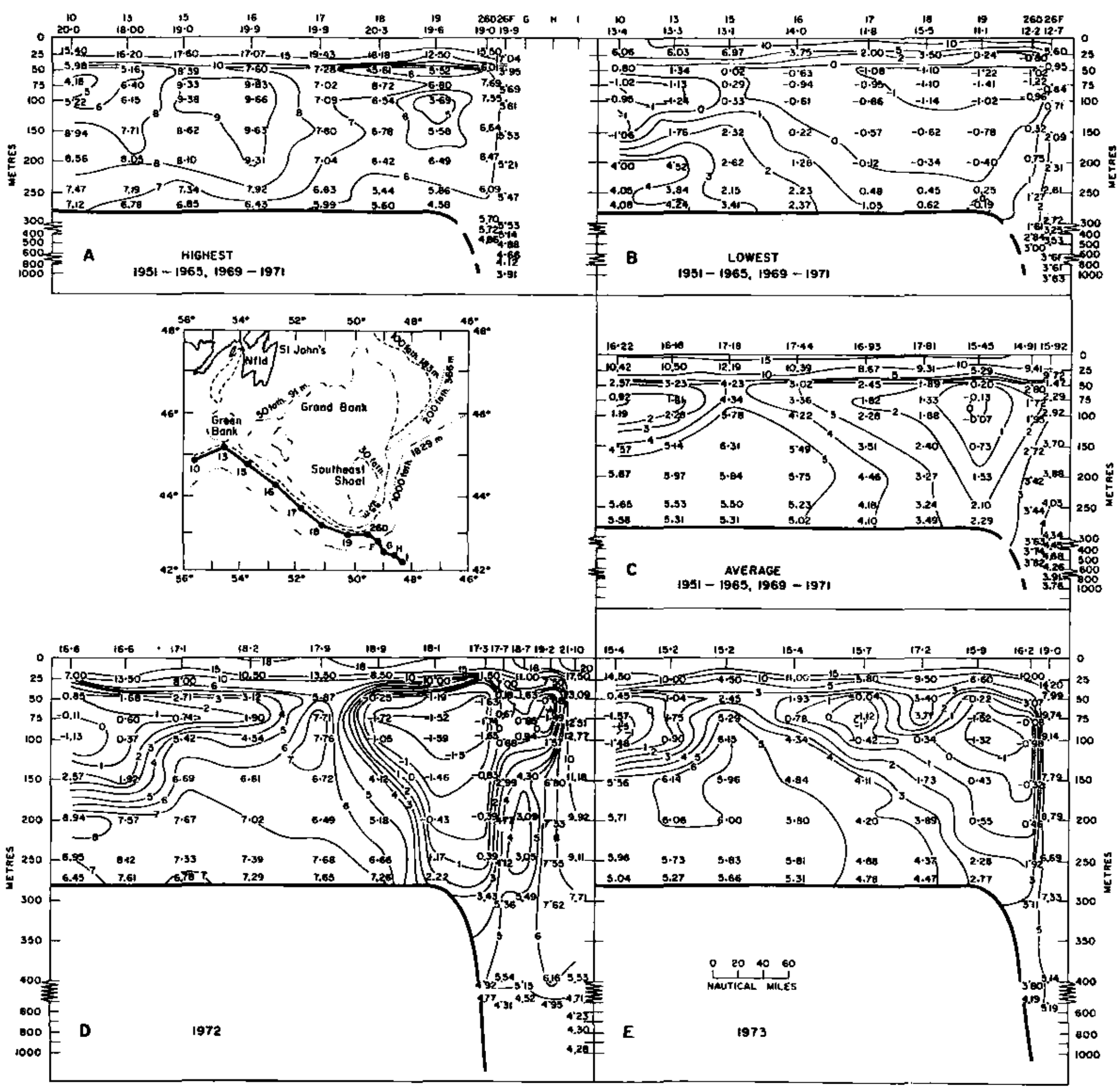

Fig. 6. Temperatures in Section F, Southwest slope Grand Bank-St. Pierre Bank: A, highest; B. lowest; and C, average; for the period 1951-65, 1969-71, ca. 11-26 August, mean dates ca. 19-21 August; and D and E for 21-24 August 1972 and 18-20 August 1973.

Section F, southwestern slope Grand Bank-St. Pierre Bank

For Section F (Fig. 6) the detailed description will apply only to the seven Stations 10-19, at 275 m, because temperatures at Stations 26D-I have already been included and described as part of Fig. 5. The latter stations will, however, be partially included in the general summary of the section.

1972. In Section F at about 275 m along the southwestern slope of the Grand Bank to St. Pierre Bank in 1972 (Fig. 6D), surface temperatures at all except Station 15 were above the averages for the 1951-65, 1969-71 (subsequently called the 1951-71) period (Fig. 6C), but none as high as the highest for the period (Fig. 6A). At 25 m, temperatures were below-average at three and above-average at four stations but none was the lowest or the highest of the 1951-72 period. At 50 m, all temperatures, except that at Station 17, were below the 1951-71 averages but none was the lowest for the 1951-72 period. The above-average temperature was not the highest of the period. At 75 m, temperatures were below the 1951-71 averages at all stations except Station 17 and at Stations 18 and 19 were the lowest for the 1951-72 period. At Station 17 the temperature was the highest for the period. At 100 m, all temperatures, except at Stations 16 and 17, were below the 1951-71 averages and at Stations 10 and 19 were the lowest of the 1951-72 period. At Station 17, the temperature was the highest for the period. At 150 m, the 2 temperatures at the western colder extreme and the temperature at Station 19 at the colder eastern end of the section were below average and at Station 19 was the lowest of the 1951-72 period. None of the above-average temperatures in the warmer central section between Stations 15-18 was the highest for the period. At 200 m, temperatures were above-average at all stations except Station 19 where the temperature was the lowest of the 1951-72 period. The temperature at Station 10 was the highest for the period. At 250 m, the temperature at Station 19 was below average but not the lowest of the 1951-72 period. Temperatures were above average at the remaining stations and at Stations 13, 17 and 18 were the highest for the period. At 275 m, temperatures at six of the stations were above average, and four were the highest of the 1951-72 period. The temperature at this depth at Station 19 was slightly below average.

1973. In Section F in 1973 (Fig. 6E), surface temperatures were below the 1951-71 averages at the six western stations but none were below the lowest for the 1951-71 period. At Station 19, the surface temperature was above average but not the highest for the above period. At 25 m, temperatures were below the 1951-71 averages at three and above average at four stations. The temperature at Station 15 was the lowest of the 1951-73 period but none of the above-average temperatures was the highest of the period. At 50 m, temperatures at all stations except Station 18 were below the 1951-71 averages and at Stations 10 and 13 were the lowest of the 1951-73 period. The above-average temperature at Station 18 was not the highest for the period. At 75 m, temperatures at four stations in the colder parts of the section were below average, at Stations 10 and 17 the lowest of the 1951-73 period and at Station 19 equal to the previous low temperature, that of 1972. None of the above-average temperatures was as high as the highest for the period. At 100 m, temperatures at all except the central Stations 15 and 16 were below average, at the western and eastern Stations 10 and 19 below the lowest of the 1951-71 period and at Station 10 the lowest of the 1951-73 period. The above-average temperatures at Stations 15 and 16 were below the highest for the 1951-71 period. At 150 m, temperatures were below average at the two central Stations 15 and 16 and the two eastern Stations 18 and 19 but in none were they below the lowest of the 1951-71 period. The above-average temperatures were not the highest of the period. At 200 m, temperatures were below average for the 1951-71 period at three stations and above average in four, but none of them were as low as the lowest or as high as the highest for the period. At 250 m, all temperatures were above average but none of them were as high as the highest of the 1951-71 period. At 275 m, temperatures at two stations were lower and at the remaining five higher than the 1951-71 averages but none were as low as the lowest or as high as the highest of the 1951-71 period.

GENERAL SUMMARY

Section A, Seal Island-Hamilton Inlet Bank

In 1972 in the Seal Island to Hamilton Inlet Bank section (Fig. 1), the intermediate colder part of the Labrador Current was on the whole colder and extended further seaward and to greater depths seaward than in any previous year of the 1951-65, 1969-71 period (subsequently in this section called the 1951-71 period.) This was especially true of the water with temperatures below -1.5°C, which was much greater in volume than in any previous year, even when judged by the increased area provided by a section including the lowest temperatures of all previous years of the 1951-71 period (Fig. 1B). In the deep water of 200 m and greater at the most seaward station, where the major influence was the

West Greenland sector of the Labrador Current, temperatures were above average, some close to and others slightly higher than any previously encountered.

In 1973, many temperatures in the colder intermediate-level portion of Section A were lower than those at the same station and level for the 1951-71 period, but the intermediate-level temperatures were not as low and the volume of water below -1.5°C not nearly as great as in 1972. In 1973, temperatures in the deep water of the Continental slope, especially related to the West Greenland Current, were lower than in 1972 and, at the greatest depths sampled, comparable with or lower than the lowest of the period 1951-72.

Section B, off Cape Bonavista.

In the Cape Bonavista section in 1972 (Fig. 2) temperatures down to 200 m were below the 1951-71 averages and, especially in the central part of the cold water, often the lowest of the 1951-72 period. The lowest temperatures both near the coast and offshore were lower than any encountered previously and water at -1.5°C and lower occurred farther seaward than in any previous year. Compared with the Seal Island section, however (Fig. 1), the Cape Bonavista section in 1972 did not show a comparably large volume of water below -1.5°C. In the deeper water of the eastern slope, intermediate temperatures prevailed.

In Section B in 1973, temperatures between 25 and 200 m and deeper at the coastward stations were generally below the averages and often below the lowest of the 1951-71 period, and many were the lowest of the 1951-73 period. The lowest temperatures were below those of 1951-71 and similarly low as in 1972. Coastwise, lower temperatures below -1°C and 1°C extended more deeply than in any previous year of the 1951-73 period. In the offshore deep slopewater of 400 m and deeper, temperatures were below average but not the lowest of the 1951-73 period.

Section C, St. John's-Flemish Cap

In the St. John's to Flemish Cap section (Fig. 3) in 1972), temperatures in the Avalon Channel at 100 m and deeper were generally lower and colder water extended more deeply than in any previous year of the 1951-72 period. In the offshore portion of the colder section of the Labrador Current to the east of the Grand Bank the water was colder than previously encountered and water below -1.5°C occupied more volume. For the first time in the 1951-72 period, water below 1°C, 0°C and -1°C was present as far seaward as Flemish Cap.

The general temperature picture for Section C in 1973 showed more cold water below -1.5°C in the Avalon Channel, reaching bottom over more area and extending farther seaward over Woolfall Bank to the Grand Bank, than in any previous year of the 1951-73 period. Low temperatures of -1.4° to -1.5°C covered the surface of the Grand Bank along the 47° latitude line of the section. In no previous year of the 1951-73 period did temperatures fall below -1.1°C over Woolfall Bank or below -1.2°C over the surface of the Grand Bank in the line of the section. The cold branch of Labrador Current water east of the Grand Bank was lower in temperature than in any previous year of the period except 1972. There was colder water and a greater volume of water below 2°C above Flemish Cap than in any year of the 1951-73 period except 1972.

Section D, St. John's-Southeast Shoal

In the St. John's to Southeast Shoal section (Fig. 4) in 1972, the deeper water of the Avalon Channel was colder and lower temperatures were present near-bottom than in any previous year of the 1951-71 period for which temperatures were recorded in Section D. Temperatures of the small amount of water below -1.5°C to the east of the Southeast Shoal were also slightly lower than those previously observed.

Considered generally, temperatures in Section D in 1973 were lower in the Avalon Channel, and especially near bottom, than in any previous year, the most comparably cold year being 1972. On the western slope of the Grand Bank at Stations 29-31, near-bottom temperatures were much lower than in any previous year and near-bottom temperatures on the Southeast Shoal were also much lower than usual. Comparable with the unusual appearance of water below 1°C and a large amount below 2°C above Flemish Cap, there was an unusually large volume of cold Labrador Current water below 0°C and some below -1°C to the east of the Southeast Shoal but separated from and extending well to the east of the usual cold Labrador Current water fringing the eastern side of the Grand Bank.

Section E, Green Bank-Southeast Grand Bank

In the Green Bank to Southeast Grand Bank section (Fig. 5) in 1972, near-bottom temperatures over Green Bank and temperatures in the colder water in the western part of the Haddock Channel were slightly lower than any previously recorded in our sections. In the eastern cold-water branch of the Labrador Current, temperatures below -1.5°C were recorded for the first time in the 1951-72 period and the amount of water below -1°C was greater than that recorded for any previous year of the period.

In Section E in 1973, there was colder water near bottom on Green Bank and in the Haddock Channel than in any previous year of the 1951-73 period. It is noticeable in all sections of Fig. 5 that this cold Labrador Current water which has come southward in the Avalon Channel naturally turns to its right to pass on the western side of the Haddock Channel. There was also colder water near bottom than in any previous year of our records on the western Grand Bank at Stations 20-22 near the Haddock Channel. Temperatures in the eastern branch of the colder part of the Labrador Current were lower than usual but not as low as in 1972.

Section F, southwestern slope Grand Bank-St. Pierre Bank

In Section F, from St. Pierre Bank along the southwestern slope of the Grand Bank (Fig. 6) in 1972, temperatures of the intermediate layer of cold Labrador Current water in the western part of the section were well below average but not the lowest of the 1951-72 period. In the eastern cold-water branch of the Labrador Current, however, temperatures of -1.5°C and lower were encountered for the first time in the period. Temperatures in the higher-temperature water at intermediate depths between the western and eastern cold water were well above average but not the highest of the period. Bottom temperatures along the slope of the Grand Bank were mostly the highest for the 1951-72 period, but at Station 19 at the edge of the eastern slope, where the influence of the eastern cold water affected the temperature, the bottom temperature was slightly below the average of the 1951-71 period.

In Section F in 1973, temperatures of the intermediate western cold layer were the lowest of the 1951-73 period. In the eastern cold intermediate layer, temperatures were below average but not as low as in 1972 and only one temperature was below the lowest temperature found in this eastern cold layer in 1951-71. Temperatures of the intermediate warmer slope-water intrusion centrally between the eastern and western cold water were close to the averages of the 1951-71 period. Near-bottom temperatures at 250-275 m were also close to average levels and lower than in 1972.

Related Effects on Fish

Some cod usually spend the winter near the coast in the deepest water of the Avalon Channel and large numbers of cod, which summer near the Avalon Peninsula and on the Grand Bank at the Virgin Rocks and vicinity, winter and spawn on the western slope of the Grand Bank. On the western slope in spring, Woolfall Bank is a well known cod fishing ground. In 1973, near-bottom temperatures in the St. John's to Flemish Cap line near the end of July (Fig. 3E) were below -1.7°C at Station 27, below -1.6 at Station 28 in the Avalon Channel on the western slope of Woolfall Bank and at Station 34 at the crest of Woolfall Bank, and below -1.4 at Station 35 and -1.5°C at Station 36 on the surface of the Grand Bank. All of these stations except No. 27 are on the 47° latitude line and all of these temperatures are low enough to kill cod, unless they had a considerable period for acclimatization to slowly falling temperatures (Templeman, 1965b, 1965c).

Captain Lewis Antle of the trawler *Atlantic Toni* from Marystown, Newfoundland reported dead cod taken in fishing in the following positions in May 1973: (1) 47°00'N, 51°40'W (western slope Woolfall Bank, 22 nautical miles east of Station 28); (2) 47°15'N, 51°20'W (Avalon Channel a little north of Woolfall Bank, 25 nautical miles approximately 35° north of west from Station 34); (3) 47°00'N, 50°05'W (Northeast Grand Bank, 5 nautical miles west of Station 35). Captain Antle reported that he caught 10-12 dead cod per tow of approximately 1 hour. In the first tow, the dead fish (all large steak cod approximately 65 cm long) looked fairly fresh as if they had just died. In subsequent tows, however, the fish were in a fairly high condition of decomposition. Captain Antle also reported that Captain Gordon Skinner took over 4,500 kg of dead fish during his trip at the same time. In addition to the dead cod there was a considerable amount of flounder (presumably American plaice) taken that appeared frozen upon hitting the deck. Farther southward along the near the section St. John's-Southeast Shoal, 1973 (Fig. 4E), Captain C. Mitchell of the Newfoundland trawler *Zonnemaire* reported that at 46°25'N, 52°25'W in

May 1973 he had one set in which he took 700 kg of flounder which were stiff and dead and were subsequently discarded. He then left the area. This locality is in the Avalon Channel on the western slope of the Grand Bank, 57 nautical miles west of Station 29 of Fig. 4. Also, Captain Owen Power of the Newfoundland trawler *Zagreb* reported that in May 1973 at 45°55'N, 50°40'W he took several tows and obtained dead flounder similar to those taken by the *Zonnemaire*. All were discarded. This locality is 14 nautical miles approximately 35° east of north from Station 30. At both Stations 29 and 30 in mid-August 1973, near-bottom temperatures were below -1.4°C. There were no reports of dead cod taken.

Although most of the dead cod taken were very likely killed naturally by cold water, it is less certain whether the flounders were previously dead or whether they froze after death on the way up. However, the time taken in lifting the trawl does not appear great enough for the latter to have occurred unless it happened suddenly for supercooled fish by ice-crystallization which is unlikely in May in this area. The discarding of flounder indicates that they were in poor condition and not frozen in the net. The large cod may be more likely than the smaller cod to be killed by cold (Templeman and Fleming, 1965c). Temperatures are not available for May from the localities of these commercial cruises in this month, but at Station 27, 176 m, 2 nautical miles off Cape Spear near St. John's, where surface to bottom temperatures are taken throughout the year, temperatures in April and May were -1.68° to -1.75°C at 75 to 125 m and near-bottom and bottom temperatures at 150 and 176 m from -1.51° to -1.73°C. Temperatures at Station 27 in July-August, from 100 to 176 m, ranged from -1.48° to -1.74°C. There is thus good reason to believe that temperatures were at least as low in May as in July-August in the areas where fish deaths were reported.

In addition to killing cod, the unusually low bottom temperatures extending so far eastward in 1973 may have driven cod farther offshore and to deeper water than usual. The Newfoundland landings of cod from ICNAF Division 3L, from which these low temperatures and cod deaths were reported, were at an unusually low level in 1973, being provisionally reported at 26,000 metric tons compared with 50,000 in 1972, 49,000 in 1971, 66,000 in 1970and 84,000 in 1969. Almost all of these landings came from the inshore and neighbouring areas, and only a small percentage, 5% in 1973, were taken by trawlers in offshore waters.

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Water Temperature in the Labrador and Newfoundland Areas in 1972 Compared with 1971 and 1973

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Introduction

Hydrological observations in the Labrador and Newfoundland areas were made in 1971, 1972 and 1973 on standard sections (Fig. 1). Temperature was measured from the surface to the bottom in the bank areas, and to a depth of 2000 m on the slope of the Continental Shelf. Investigations were conducted by R/V *Protsion* in December 1971-February 1972, in April-June 1972 and in April-June 1973, by R/V *Perseus* III in April-July, 1972, October 1972 and in May-September 1973, by the scouting vessel *Neptun* in August 1973, and by R/V *Artemida* in November 1973.

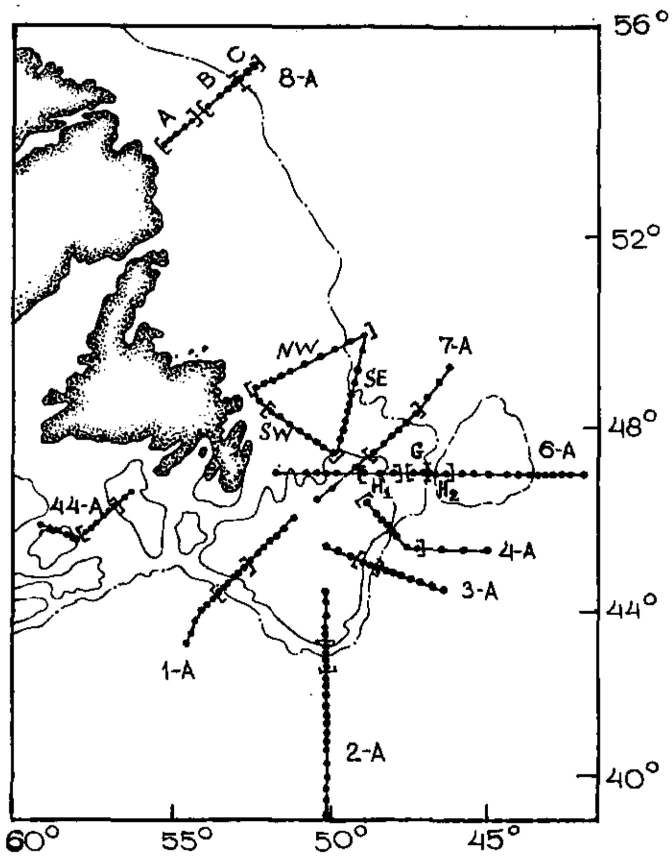

Fig. 1. Water temperature in the Labrador and Newfoundland areas in 1973.

Methods

Temperature anomalies for the 0-200 m layer in different sections were determined by the method previously described by the author (Burmakin, 1972). Sectors of the sections, as suggested by Elizarov (1962) and Burmakin (1972) for the calculation of the average temperature in different layers, are shown in brackets in Fig. 1.

Results

As is evident from Table 1, considerable negative anomalies of temperature, up to -2.2°C in the 0-200 m layer were found during December 1971-October 1972 over the whole area, except on the southern slopes of Grand Bank where positive anomalies from 0.5°C to 2.2°C were recorded (Section 2-A), on the south-western slope of Grand Bank in May and June where positive anomalies of 0.3°C and 0.8°C were found (Section 1-A) and on the south-western slope of St. Pierre Bank (Section 44-A) where a positive anomaly of 1.2°C was registered in May. The greatest negative anomalies were observed in the cold waters of the Labrador Current and the greatest positive anomalies were to the south of Grand Bank.

From Table 2, it can be seen that in the Spring of 1973, after the extreme cooling of waters during 1972, negative anomalies of temperature in the 0-200 m layer still remained throughout the Labrador-Newfoundland area, with the exceptions of the southern slope of Grand Bank and Cabot Strait where positive anomalies were found in April, the former being at a maximum value of 3.4°C. The maximum negative anomaly of -2.6°C was recorded on the eastern Grand Bank on Section 4-A in May. During the summer, the anomalies varied around the long term mean off Labrador and north of the Grand Bank (Sections 8A and Triangle NW, SW, SE) but were always negative on the Grand Bank and in Cabot Strait (Sections 6-A, 3-A, 44-A). Only one set

TABLE 1. Temperature anomalies in the 0-200 m layer (°C) at the end of 1971 and during 1972.

	1971	1972					
Sections and dates	Dec	Jan	Feb	Apr	May	June	Oct
8-A(B) 27 Oct	-	-	-	-	-	-	-1.4
7-A 9 Dec., 7 Feb, 3 May	0.0	-	-0.8	-	-1.5	-	-
6-A(G) 14 Dec 10 Apr, 1 May 26 May	-0.9	-	-	-2.2	-1.1;-1.9	-	-
4-A 20 Dec 25 Apr, 20 May	-1.3	-	-	-0.8	-0.9	-	-
3-A 25 Dec 18 Apr, 16 May	0.0	-	-	-1.3	-0.8	-	-
2-A 27 Dec 23 Apr, 5 June	+2.2	-	-	+0.5	-	+1.0	-
1-A 8 Jan 7 May, 19 June	-	-0.1	-	-	+0.3	+0.8	-
44-A 20 Jan 18 May, 27 June	-	-0.6	-	-	+1.2	-1.0	-

TABLE 2. Temperature anomalies in the 0-200 m layer (°C) in 1973.

Sections and dates	Apr	May	June	July	Aug	Nov
8-A(B) 23 June, 9 Aug, 2 Nov.	-	-	-1.2	-	-0.3	-0.2
triangle (NW) 3 June, 3 Aug	-	-	-1.0	-	0.0	-
triangle (SW) 2 June 31 July	-	-	-1.1	0.0	-	-
triangle (SE) 1 June, 1 Aug	-	-	-1.0	-	0.3	-
7-A 28 May	-	-1.0	-	-	-	-
6-A (G) 27 Apr 24 May, 13 July	-1.0	-0.1	-	-1.8	-	-
4-A 19 May	-	-2.6	-	-	-	-
3-A 15 May, 11 July	-	-0.8	-	-0.5	-	-
2-A 14 Apr, 1 May	+3.4	-0.8	-	-	-	-
44-A 22 Apr, 3 June	+0.5	-	-1.0	-	-	-

TABLE 3. Average temperature in the 0-200 m layer (°C) relative to stated dates and its anomalies in 1972.

Sections	15 Apr	15 May	15 June	15 Nov
8-A (AB)	-	-	-	-0.15 (-1.05)
7-A	-	-0.52 (-1.36)	-	-
6-A(G)	-	0.01 (-1.17)	-	-
4-A	0.33 (-0.50)	1.04 (-0.22)	-	-
3-A	-0.93 (-1.28)	-0.14 (-0.62)	-	-
2-A	1.67 (+0.62)	2.39 (+1.01)	3.13 (+1.14)	-

TABLE 4. Average temperature in the 0-200 m layer (°C), relative to stated dates, and its anomalies in 1973.

Sections	15 May	15 June	15 July	1 Nov
8-A (A)	-	-	-0.18 (+0.09)	0.07 (-0.35)
8-A (B)	-	-	-0.26 (-0.41)	1.22 (+).07)
8-A (C)	-	-	3.48 (-0.16)	3.41 (-0.29)
8-A (AB)	-	-	-0.20 (-0.11)	0.72 (+0.03)
7-A	0.07 (-0.44)	-	-	-
6-A (G)	1.18 (0.00)	-	-	-
4-A	-0.64 (-2.80)	-	-	-
3-A	-0.24 (-0.96)	-	-	-
44-A	-	2.20 (-1.13)	-	-
Norms were calculated for periods	1968-72	1966-73	1936-61	1964-72

TABLE 5. Average temperature in the 0-200 m layer (°C) and its anomalies on Section 8-A on 1 November and on Sections 7-A, 6-A (G) 4-A, 3-A on 15 May 1968-1972.

Year	Sections and dates				
	8-A 1 Nov	7-A 15 May	6-A(G) 15 May	4-A 15 May	3-A 15 May
1968	0.50	1.25	1.48	2.25	1.85
1969	0.50	0.70	1.99	3.46	0.80
1970	0.60	0.87	1.95	2.05	0.44
1971	0.57	0.26	0.46	2.01	0.65
1972	-0.15	-0.52	0.01	1.04	-0.14
Average	0.40	0.51	1.18	2.16	0.72
1972 Anomaly	-0.55	-1.03	-1.17	-1.12	-0.86

of observations was made in the autumn, on Section 8-A, where the anomaly was -0.2°C. Thus, during 1973, negative anomalies decreased in the areas north of Grand Bank, but they increased on the bank itself and in the Cabot Strait.

Tables 3 and 4 give the average water temperature and its anomalies in the 0-200 m layer over 1972 and 1973 respectively, the method of calculation being that used previously by the author (Burmakin, 1967-72) and Elizarov (1962). It is clear that the anomalies in Tables 1 and 3, and 2 and 4 respectively are comparable and either set could reasonably be used for analyses of temperature changes in the areas investigated.

As previously stated by Burmakin (1972), inter-annual changes in average temperature in the Labrador Current usually have cycles of 3-4 years. The last cycle started in 1968 and probably ended in 1972. This cycle included two temperature warm years (all anomalies above average), 1968 and 1969, one warm year, 1970, and two cold years, 1971 and 1972. In 1972, the temperature in this area was the lowest throughout the period of observations beginning in 1936. In 1972, the temperature in the 0-200 m layer on the various sections across the Labrador Current was between 0.55°C and 1.17°C lower than the average value over the 1968-72 period as is shown in Table 5.

From Table 6, it is obvious that there was a considerable extra cooling in 1972 even compared with the cold conditions of 1971. This was greatest in the 0-50 m layer on the eastern slope of Grand Bank in April and May (Sections 6-A(H_1) and 4-A) and in the near-bottom, 200-500 m layer, on the southeastern slope of this bank in April (Section 3-A) In the case of the Labrador Current, in the 50-200 m and 0-200 m layers, cooling was lower by 0.5° to 1°C than in the 0-50 m layer.

Changes in water temperature in the various layers in 1973, as compared to 1972, an abnormally cold year, are shown in Table 7. In 1973 temperatures increased in all layers off South Labrador (section 8-A) and on the northeastern and southern slopes of Grand Bank (Sections 7-A, 6-A, 2-A), but generally decreased on the south eastern slope of Grand Bank (Sections 4-A, 3-A) and in Cabot Strait (Section 44-A). In the spring of 1973 the extra cooling was particularly noticeable on the shelf stations with depths of from 80 to 185 m along the northern and eastern Grand Bank, especially in the 50 m bottom layer but some warming was observed on the slope stations at depths of 205-1140 m between Grand Bank and Flemish Cap, mainly in the 0-50 m layer (Table 8).

On Section 1-A, across the southwestern slope of Grand Bank and on Section 44-A, across the Cabot Strait, as can be seen from Table 9, the water temperature in the 0-50 m, 0-200 m, 50-200 m, and 50-100 m layers was lower in January, May and June 1972 than in 1967, 1970 and 1971, but in the near bottom layer, 100-200 m, and especially in the 200-500 layers of these sections the temperatures were generally higher. Thus during the years 1970-72, the heating effect of the Gulf Stream on the near-bottom layers to the south of

TABLE 6. Average temperature in different layers (°C) in spring and summer, 1971-72.

Sections	Date	Water layers (m)			
		0-50	0-200	50-200	200-500
"Triangle"	7 May 71	0.83	0.23	-0.45	-
(SE - side)	14 May 72	-0.64	-0.74	-0.84	-
"Triangle"	7 May 71	0.92	-0.04	-0.64	-
(SW - side)	14 May 72	-0.63	-0.91	-1.08	-
	2 June 71	2.29	0.44	-0.69	-
	28 May 72	0.04	-0.56	-1.04	-
	10 July 71	4.02	0.87	-0.82	-
	1 July 72	3.34	0.66	-1.07	-
7-A	3 May 71	-0.05	0.07	0.07	2.84
	3 May 72	-0.90	-0.70	-0.65	1.22
6-A (H_1)	1 May 71	0.89	0.32	-0.38	-
	2 May 72	-0.48	-0.76	-1.02	-
	25 May 71	2.74	1.30	-0.25	-
	26 May 72	0.44	0.04	-0.76	-
6-A (G)	30 Apr 71	0.25	0.65	0.74	3.29
	1 May 72	-0.19	0.25	0.40	2.43
	24 May 71	1.25	0.35	0.05	2.86
	26 May 72	-0.35	-0.17	-0.20	2.82
6-A (H_2)	30 Apr 71	1.35	2.84	3.34	4.48
	1 May 72	1.91	2.71	2.97	4.18
	24 May 71	2.46	2.74	2.84	4.56
	26 May 72	1.72	2.26	2.43	3.68
4-A	25 Apr 71	2.72	2.25	1.63	4.48
	24 Apr 72	0.40	0.57	0.57	3.54
	18 May 71	2.60	2.07	1.20	4.28
	20 May 72	1.16	1.16	0.94	3.68
3-A	20 Apr 71	0.62	0.32	-0.22	1.78
	23 Apr 72	-0.88	-0.95	-1.02	-0.27
	15 May 71	1.37	0.66	-0.16	2.68
	16 May 72	0.38	-0.10	-0.57	1.00

TABLE 7. Average temperature in different layers (°C) in 1972 and 1973.

Sections	Date	Water layers (m) 0-50	50-200	0-200	200-500
8-A (BC)	27 Oct 72	0.76	1.16	1.05	2.49
	2 Nov 73	2.31	2.24	2.25	2.66
7-A	15 May 72[a]	-0.28	-0.61	-0.51	1.11
	15 May 73[a]	0.26	-0.05	0.07	1.85
6-A (H_1G)	26 May 72	0.00	-0.69	-0.27	2.82
	25 May 73	1.12	-0.42	0.25	3.13
4-A	20 May 72	1.16	0.94	1.16	3.68
	19 May 73	0.13	-1.25	-0.56	1.90
3-A	16 May 72	0.38	-0.57	-0.10	1.00
	15 May 73	0.59	-0.89	-0.24	2.13
2-A	23 Apr 72	2.33	1.59	1.86	3.41
	23 Apr 73[a]	2.71	2.71	2.73	4.26
44-A	15 June 72[a]	4.23	3.18	3.44	6.04
	15 June 73[a]	3.64	1.73	2.20	4.55

[a] Temperature is transformed to one date according to average diurnal rates of change in temperature.

TABLE 8. Average temperature of different layers (°C) on the shelf and slope of the Grand Bank in the Spring of 1972 and 1973.

Sections	Date	Water layers (m) 0-50	50-200	0-200	200-500
Triangle (SW side)	28 May 72	0.04	-1.04	-0.56	-
Shelf	2 June 73	0.01	-1.64	-1.01	-
6-A (H_1)	26 May 72	0.44	-0.76	0.04	-
Shelf	24 May 73	0.60	-1.45	-0.37	-
6-A (G)	26 May 72	-0.35	-0.17	-0.20	2.82
Slope	25 May 73	2.21	1.45	1.63	3.13

TABLE 9. Average temperatures in different layers (°C) in January, April-June 1972, and in 1966, 1967, 1970 and 1971.

Sections	Date	Water layers (m) 0-50	0-200	50-200	50-100	100-200	200-500
2-A	3 Apr 71	1.44	0.77	0.23	-0.11	0.99	2.94
	23 Apr 72	2.33	1.86	1.53	2.18	2.98	3.41
	13 June 66	3.66	2.77	2.26	1.95	2.56	3.30
	5 June 72	3.86	2.89	1.62	0.45	4.16	4.84
1-A	12 Jan 70	6.89	6.39	5.51	5.82	7.22	5.94
	8 Jan 72	3.51	4.47	4.86	4.49	8.72	7.68
	1 May 67	2.98	2.62	2.45	2.45	2.70	3.37
	7 May 72	2.70	2.80	2.60	2.34	5.87	6.84
	19 June 71	8.11	6.86	4.96	4.98	7.09	5.29
	18 June 72	6.16	5.01	3.66	2.82	6.44	7.02
44-A	17 Jan 70	3.90	3.92	3.93	2.65	4.57	4.96
	20 Jan 72	1.43	2.04	2.25	1.39	2.67	5.33
	24 May 71	3.18	3.28	3.59	2.07	3.78	5.18
	18 May 72	2.04	3.08	3.43	1.29	4.52	6.57
	20 June 70	6.35	4.08	3.32	1.95	4.00	5.36
	27 June 72	5.19	3.60	3.07	1.96	3.62	5.80

Grand Bank and St. Pierre Bank was highest in 1972 at the same time that the greatest winter cooling since 1936 (when observations began) occurred over the remainder of the Grand Bank, Newfoundland and Labrador areas.

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The Current System East of Newfoundland Grand Bank

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Introduction

In recent years there have been two schools of thought concerning the derivation of the North Atlantic Current in the region Southeast of Newfoundland Grand Bank. The first is due to Worthington (1962) who argued that the North Atlantic current system was essentially composed of two gyres separated by a trough of low pressure running in a southeasterly direction from the Tail of the Banks, roughly coincident with the Southeast Newfoundland Rise. Immediately south of the Rise, and making up the northern part of the southern gyre, he identified the Gulf Stream proper running southeasterly, with the Slope Water Current along its northern edge. The Atlantic Current, regularly reported by the United States Coast Guard's International Ice Patrol to the east of Grand Bank (Soule 1951, Kollmeyer *et al.* 1966, Moynihan and Andersen 1971), he maintained was part of the northern gyre. The two current systems had very similar temperature-salinity curves, but Worthington showed that in the oxygen minimum layer of the Atlantic Current, values were some 0.5 *ml/l* higher than in the corresponding layer of the Gulf Stream and hence he deduced that there was minimal transport between the two current gyres.

Mann (1967) considered that the current system was as shown in Fig. 1, the Slope Water Current mixing with a branch of the Gulf Stream which separated from the main part of the Gulf Stream in the vicinity of 38°30'N, 44°W and curved back in a northwesterly direction to form the Atlantic Current. Mann explained that the higher oxygen content of the Atlantic Current could have originated from a clockwise gyre to the east of the Atlantic Current, where overturning occurred in winter down to a depth of at least 400 m.

However, Clarke and Reiniger (1974) have suggested a possible mechanism for explaining the formation and development of the oxygen minimum which could produce the relatively higher oxygen values found in the Atlantic Current, and have concluded that the oxygen minimum may not be a reliable tracer of advection in this area.

Aim

In April and May 1972, three ships took part in a co-operative physical and chemical oceanographic study of the region in an attempt to resolve this controversy. They were R/V *Hudson* from Bedford Institute of Oceanography, R/V *Chain* from Woods Hole Oceanographic Institute and R/V *Cirolana* from MAFF, Fisheries Laboratory, Lowestoft. The intention in this paper is to provide a preliminary and descriptive account of the oceanography of the most northerly part of the survey area, the part allocated to R/V *Cirolana*. It is hoped that a subsequent joint publication will report the complete three-ship survey in a more comprehensive and analytical manner.

Method

The hydrographic sections worked by *Cirolana* are also shown in Fig. 1. The first crossed the Labrador Current between Flemish Cap and the Grand Bank. Three current meter moorings were laid on this section at positions shown as A, B and D in Fig. 1, both to monitor the current velocity and variability and to provide a reference level for geostrophic calculations. The other two sections extended in a southeasterly direction, towards the Azores, and were perpendicular to the expected flow of the Slope Water Current and the Atlantic Current; they reached 41°W longitude, and it was hoped that they would penetrate the gyre which Mann maintained was the source of the high oxygen content of the Atlantic Current. Temperature, salinity, oxygen and silicate were measured down to the bottom, or in the deeper water alternately to 2,300 and 4,500 m, and XBT probes were launched between series stations to provide more detailed temperature coverage in the surface layer.

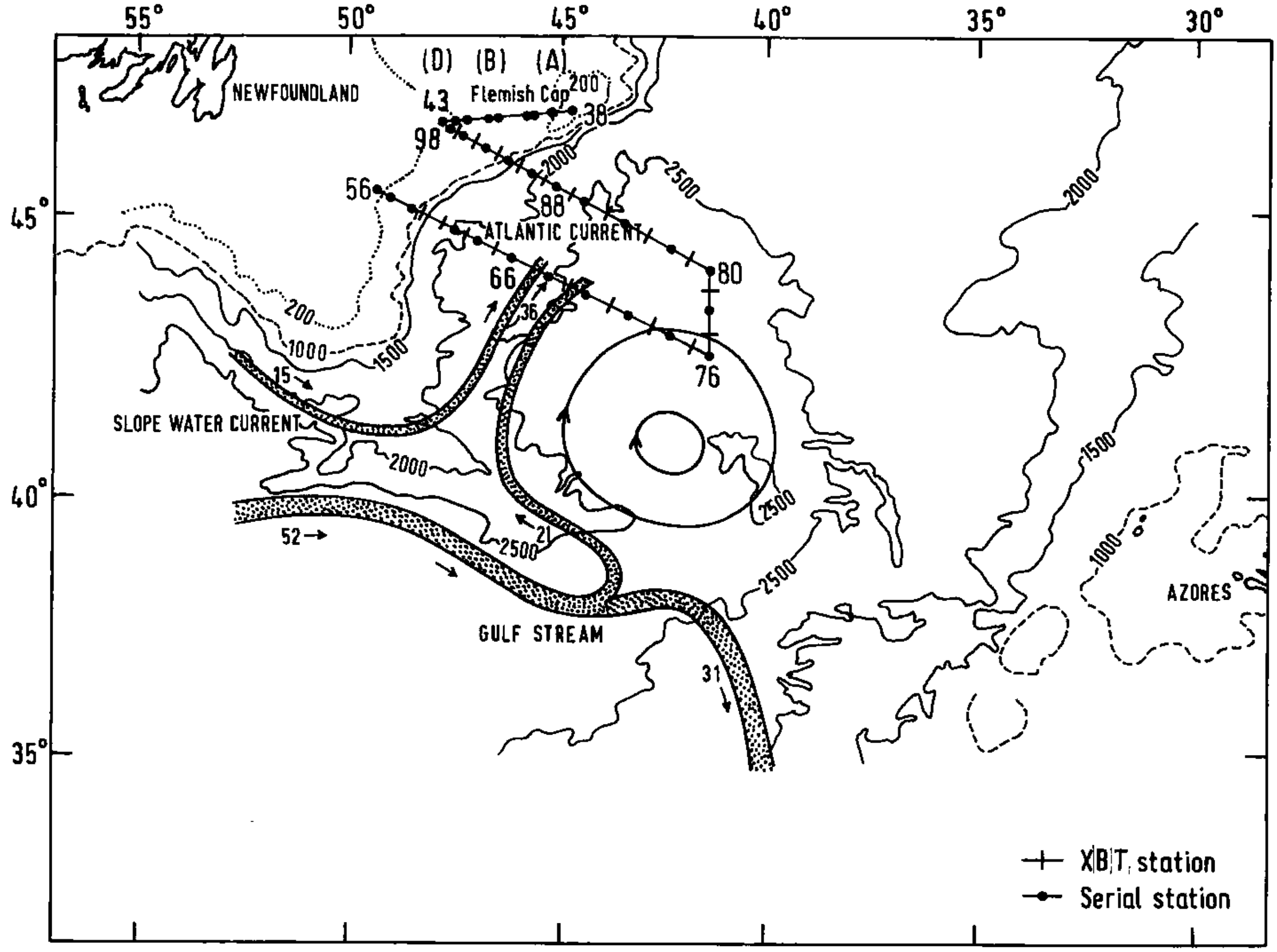


Fig. 1. The current system southeast of the Grand Bank. Nominal transport in million tonnes per second (based on Mann 1967) with *Cirolana* stations superimposed.

Salinity samples were analyzed using an Auto Lab inductive salinometer; oxygen analysis was carried out by the Carritt and Carpenter (1966) version of the Winkler technique, and silicate by the manual method of Strickland and Parsons (1968).

Results

The temperature, salinity, oxygen, silicate and sigma *t* sections for the Flemish Cap-Grand Bank section are shown in Fig. 2. The low temperature, low salinity, high oxygen Labrador Current can be clearly seen on the edge of the Grand Bank, flowing in a southerly direction, while the deep water in the Channel is composed of North Atlantic Central water of similar characteristics to that which might be expected at depths greater than 800 m throughout the survey area. The silicate distribution shows an increase with depth in the surface region, with a layer of maximum silicate concentration at about 300 m.

Moynihan and Anderson (1971), among others from the US Coast Guard International Ice Patrol Service (USCG), have shown very similar distributions of temperature and salinity for this time of year, although our temperatures appear to be a little colder over the shallow water of Grand Bank (by 1°C or so), a reflection perhaps of the unusually bad ice conditions of 1972. USCG have not to our knowledge made oxygen and silicate observations in these waters.

The temperature and salinity distributions for the southern section (Stations 56-76), given in Fig. 3, clearly show the Atlantic Current, with associated temperatures rising to

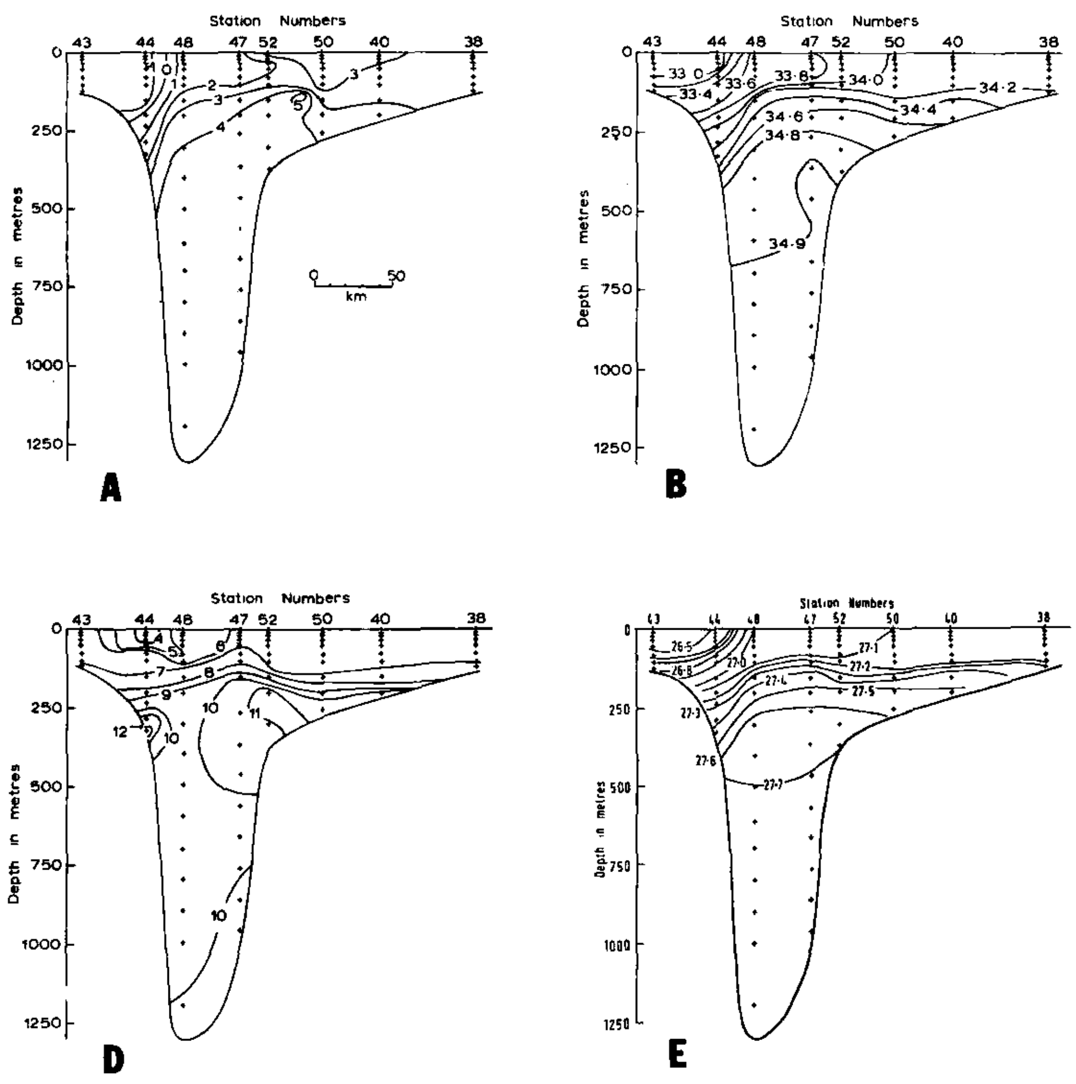


Fig. 2. Grand Bank-Flemish Cap Section: (A) Temperature, °C; (B) Salinity, °/₀₀; (C) Oxygen, ml/l; (D) Silicate, µg atoms /l.; (E) Sigma t.

16°C and salinities above 36°/₀₀. To the west of the Atlantic Current is another north-going stream of slightly lower temperature and salinity (11°C and 35°/oo), which might be thought to be Mann's Slope Water Current. A counter-current flows between these two north-going streams, while the Labrador Current can again be seen over the edge of Grand Bank.

On the more northerly section (Stations 78-98, but note the change of direction east of Station 80 to include Station 78), a somewhat similar situation prevails (Fig. 4), although the "Slope Water Current" appears almost to have merged with the Atlantic Current, temperatures in the latter rising not much above 14°C.

In view of the importance attached, by Worthington and Mann, to the oxygen content of the water masses in the area, it is worth noting the salient features in the distribution of this paramenter in Fig. 3 and 4. The oxygen minimum layer under the main core of the Atlantic Current shows values between 3.55 and 4.0 *ml/l* on both the southern and northern sections. These levels are in accordance with the accepted values for this locality (Worthington 1962). However, whereas from Station 70 to 76 on the southern section the oxygen content of the surface layer remains reasonably steady, as indicated by the uniform depth at about 300 m of the 5.0 *ml/l* contour, on the northern section greater variability occurs, with higher oxygen values being found to twice that depth on Stations 84 and 78. At the later station an invasion of water with values greater than 5.5 *ml/l* is evident between 250 and 600 m. The greater variability of oxygen on the northern section, with an intermediate maximum above the oxygen minimum at some of the more easterly stations, is reflected somewhat, although to a lesser degree, by the configuration of sigma t which shows a greater undulation of the isopycnals on the northern section (Fig. 4E) compared with the similar area on the southern section (Fig. 3E).

Below the oxygen minimum layer values increase with greater depth to over 6 *ml/l*. It is interesting to note that on both sections there is a small area of water on the bottom near the edge of the bank with an oxygen content above 6.5 *ml/l*. This feature is reflected by the distribution of sigma *t* and salinity. It seems possible that these features indicate vestiges of Northwest Atlantic Bottom Water, described by Lee and Ellett (1967). This south-going water mass originates from overflow through the Denmark Strait across the Iceland-Greenland ridge. Its salinity, at 34.90°/₀₀, appears slightly lower than indicated by Lee and Ellett but they suggest that the composition of this water mass is subject to some variation.

The distribution of silicate in the deep water on both sections shows several features of interest. Metcalf (1969) has suggested that silicate is of great value in identifying water masses in the deeper part of the ocean, beneath the biological active surface layers. Mann *et al.* (1973) have studied the meridional distribution of silicate in the western basin of the Atlantic Ocean. Two of the most prominent features of their investigation are the north-going tongues of high silicate water associated with Antarctic Bottom Waters and Antarctic Intermediate Waters.

The distribution of silicate in the deep water on both the southern and northern sections of the present investigation (Fig. 3 and 4) indicates a tongue of high values (22-24 µg atoms/*l*) somewhat above the bottom at about 4,200 m. The study by Mann *et al.* would suggest that this feature represents Antarctic Bottom Water that has flowed northwards across the Southeast Newfoundland Rise and in overriding water of low silicate content, which consists of a mixture of North Atlantic Deep Water and remnants of Denmark Strait Overflow. The silicate values on both sections are similar to those reported by Mann *et al.* for our region. The somewhat higher maximum silicate value of 24 µg atoms/*l* on the southern section, compared with 22 µg atoms/*l* on the northern section, tends to substantiate the concept of a water mass becoming progressively diluted during its northward passage. Further to the south, Mann *et al.* have shown that the maximum silicate values in the Antarctic Bottom Water are much higher and the water mass is also clearly identified by its temperature and salinity. However, at the latitude of the present investigation temperature and salinity no longer characterize this water.

Below the oxygen minimum layer already referred to at approximately 600 m on both the northern and southern sections there is a silicate maximum at approximately 800 m. Mann *et al.* have traced such a maximum through the western Atlantic and have shown it to be Antarctic Intermediate Water originating at the Antarctic Convergence. They have shown this water mass to be closely related to potential density surfaces as it progresses northwards, and in the North Atlantic the silicate maximum is associated with a potential density of 27.4. Reference to Fig. 3 shows that on the southern section the 27.4 isopycnal is fairly well aligned with the core of the silicate maximum at 14 µg atoms/*l*. Indeed the configuration of sigma *t* closely resembles the distribution of silicate above 1,000 m. On the northern section (Fig.4) the similarity between the configuration of sigma *t* and

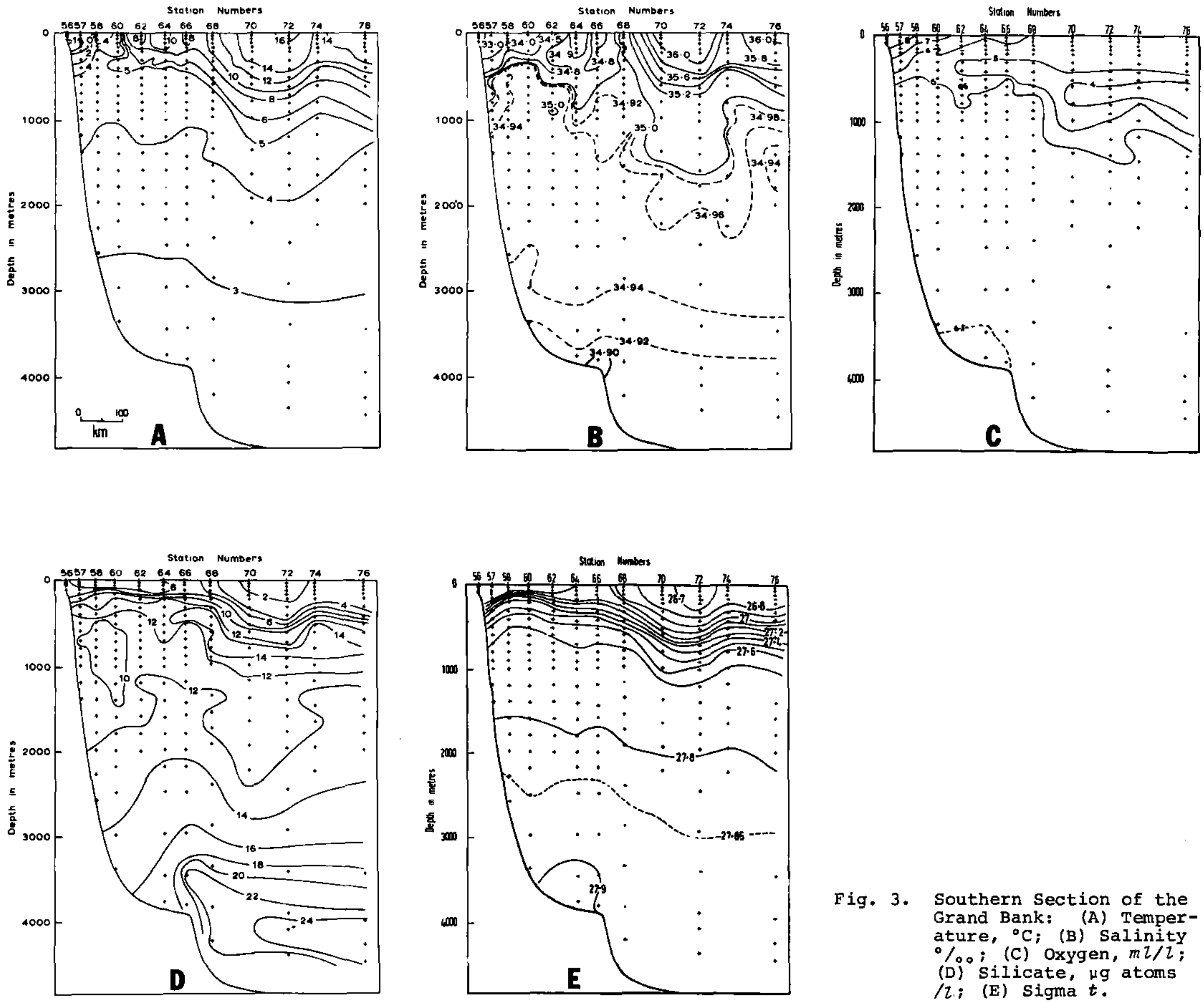


Fig. 3. Southern Section of the Grand Bank: (A) Temperature, °C; (B) Salinity °/₀₀; (C) Oxygen, *ml/l*; (D) Silicate, µg atoms /*l*; (E) Sigma *t*.

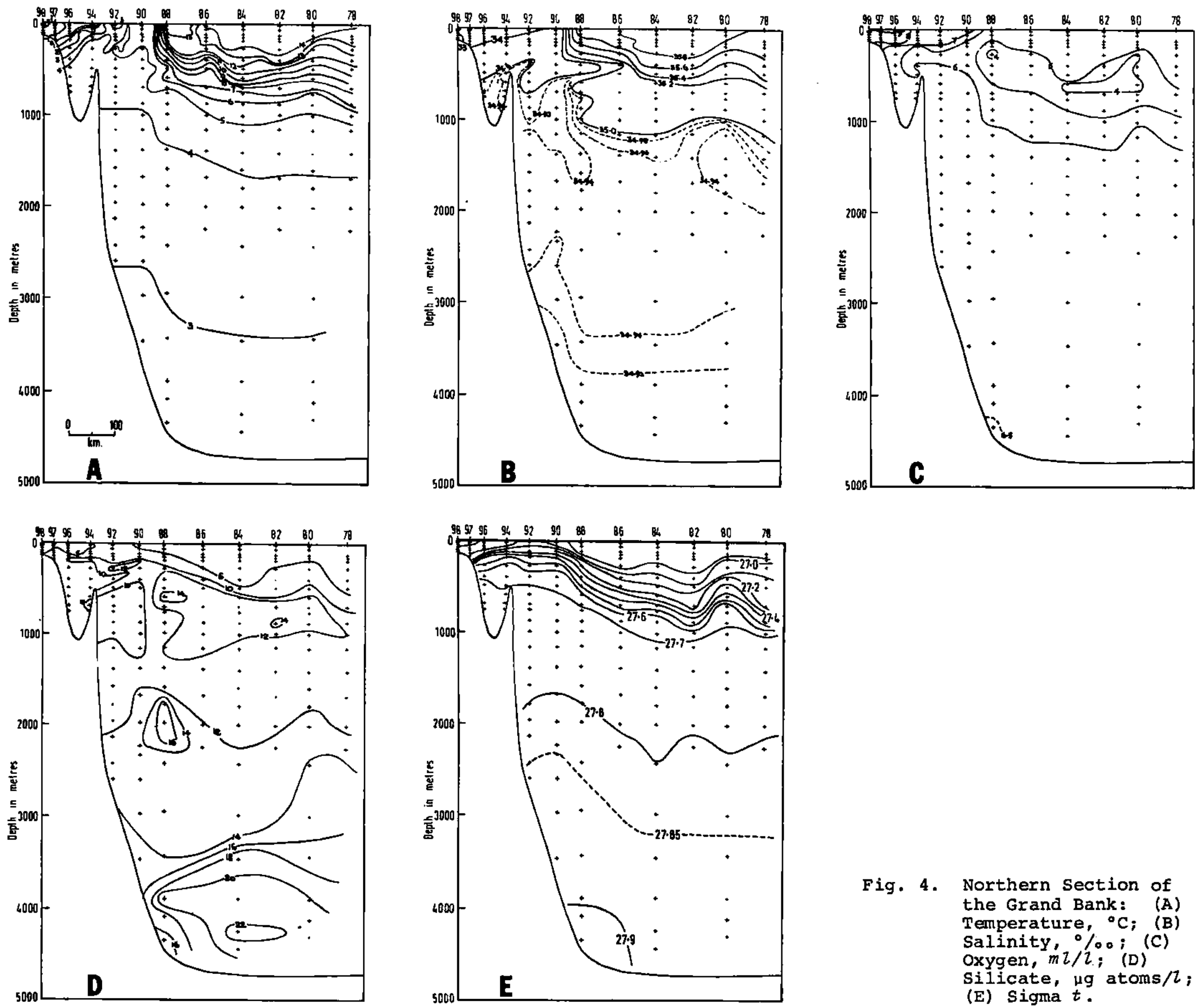


Fig. 4. Northern Section of the Grand Bank: (A) Temperature, °C; (B) Salinity, °/₀₀; (C) Oxygen, ml/l; (D) Silicate, µg atoms/l; (E) Sigma t.

silicate is not so marked, but a rather thick band of silicate values above 12 μg atoms/*l* generally occurs over the 27.4 isopycnal. The silicate maximum near 300 m on the Grand Banks-Flemish Cap section (Fig. 2) coincides with a density of approximately 27.4 to 27.6. It is therefore possible that on the present survey Antarctic Intermediate Water may be traced right up to the edge of the Grand Banks. A progressive south to north decrease in the amount of silicate in this water mass across the three sections is again indicative of dilution as it moves northwards.

A surprisingly high silicate core was found at 2,000 m on the northern section only just off the edge of the shelf (Fig. 4). This is not thought to be due to sampling errors, since high values were found at stations on either side of the main core and at several depths. We have no obvious explanation of this anomaly, although the possibility of this feature originating from a branch of the Antarctic Bottom Water seems unlikely.

The general distribution of silicate observed during this investigation fits in well with the pattern proposed by Mann *et al.* for this region. Our findings also fully substantiate Metcalf's (1969) hypothesis that silicate is a good indicator for the identification of water masses. Indeed, during the present survey the distribution of silicate has identified water masses with greater precision than the more traditional temperature and salinity labels.

Mass transport across the northern and southern sections

One of the main differences between the Mann and Worthington theories concerns the difference of mass transport between the Gulf Stream and the Atlantic Current. (In Fig. 1 the volume transports as indicated by Mann (1967) have been converted to units of mass transport for easier comparison, since these units are more commonly used in the computer programs at the Fisheries Laboratory, Lowestoft.) Mann believes that of the total Slope plus Gulf Stream Current of about 67×10^6 tonnes/sec which crosses 50°W south of the Grand Bank, 15×10^6 tonnes/sec separates as the Slope Water Current and breaks away around the Tail of the Banks following the edge of Grand Bank, while another 21×10^6 tonnes/sec separates from the Gulf Stream proper in the vicinity of 38°30'N, 44°W, eventually joining the Slope Water Current to form a total Atlantic Current transport of 36×10^6 tonnes/sec. Worthington (1962) argues that the total transport between his gyres does not exceed 10×10^6 tonnes/sec. Although we cannot solve this discrepancy on our data alone, it is interesting to compare Mann's transport for the Atlantic Current with our own.

For this purpose we have used a reference level of 2,000 m, so as to compare directly with Mann's data, and the mass transports above this level are given in Table 1 for the two longer sections which cross the Atlantic Current. It is clear that there are both north and south flowing streams crossing the sections, but the total mass transport of 27.28×10^6 tonnes/sec across the southern section is remarkably consistent with a flow of 23.87×10^6 tonnes/sec across the northern section after allowing for a flow of 2.69×10^6 tonnes/sec between Stations 76 and 80. The main north flowing streams across the two sections amount to 34.40×10^6 tonnes/sec (Stations 60-72) and 39.51×10^6 tonnes/sec (Stations 82-88), which compare favourably with the 36×10^6 tonnes/sec quoted by Mann.

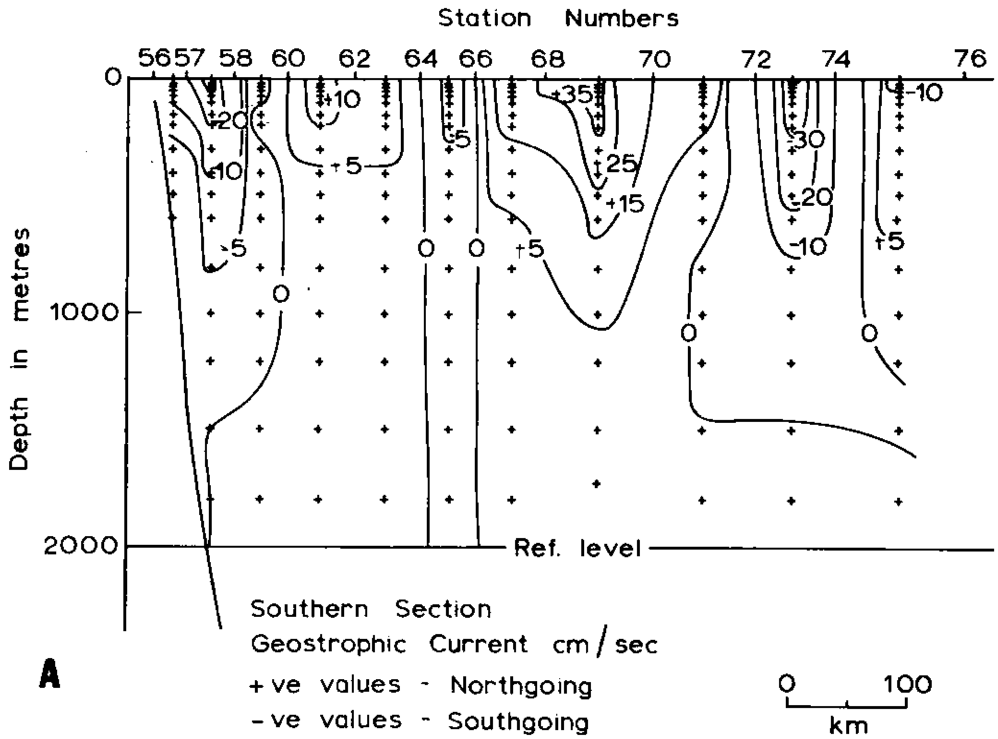
However, the separate "Slope Current" appears to have a transport of only 5.84×10^6 tonnes/sec across the southern section, compared with Mann's estimated 15×10^6 tonnes/sec, and seems to have merged with the Atlantic Current on the northern section.

TABLE 1. Mass transport between pairs of stations, in 10^6 tonnes/sec.

Stations	92-90	90-88	88-86	86-84	84-82	82-80	Total			
Transport	-0.31	-10.24	26.52	10.18	2.81	-5.09	23.87			
Stations	76-80	78-80	Total							
Transport	0.65	2.04	2.69							
Stations	58-60	60-62	62-64	64-66	66-68	68-70	70-72	72-74	74-76	Total
Transport	-0.13	2.88[a]	2.96[a]	-3.06	6.70	23.46	1.46	-14.35	7.36	27.28

Positive flow is northeast-going (for Stations 76-80, east-going)

[a] Reference level at maximum observed depth of 1800 m.



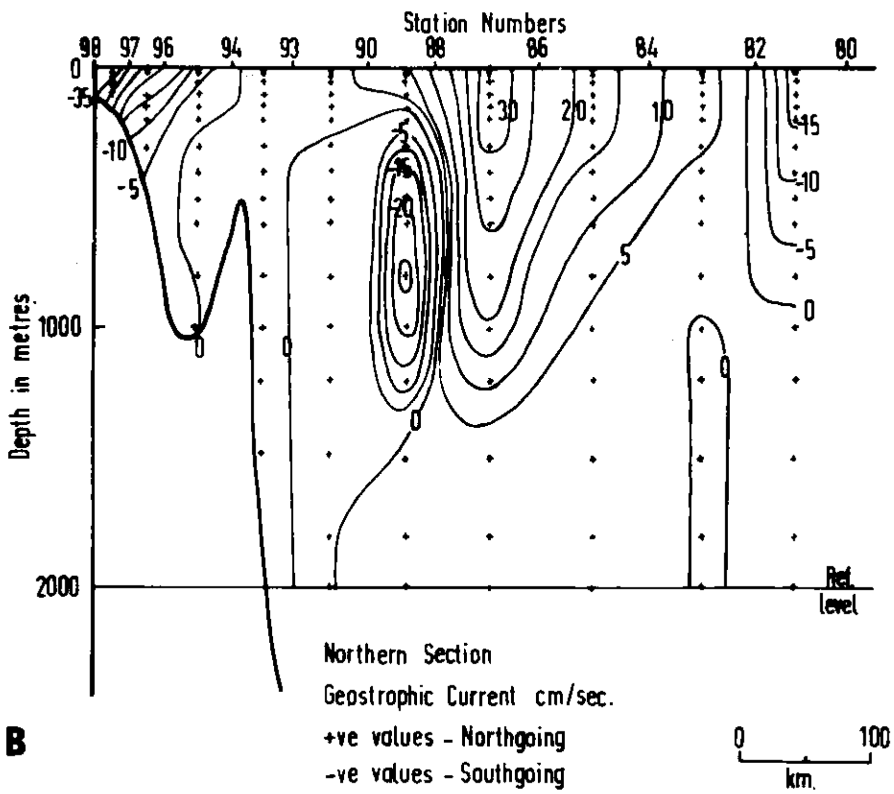


Fig. 5. Geostrophic Currents: (A) Southern Section; (B) Northern Section.

The current velocities

The speed of the Atlantic Current across the two longer sections has been calculated geostrophically, from the data presently available. Velocities over the Bank relative to the 2,000 m reference level have been computed by a modification of the method of Helland-Hansen (1934), and appear to have a maximal speed of about 40 cm/sec near the surface between Stations 68 and 70 on the more southerly section and 33 cm/sec between Stations 86 and 88 on the more northerly section. Fig. 5(A) shows the geostrophic velocities for the southern section, in which the main north-flowing Atlantic Current is seen as a wide stream with an equally strong but narrower counter-current which may be part of a gyre or meander of the main stream to the east. The maximal velocities in the north-flowing stream to the west of the Atlantic Current, earlier designated "Slope Water Current", are of the order of 13 cm/sec, while the Labrador Current has a maximum velocity of 33 cm/sec. On the northern section, Fig. 5(B), a similar situation obtains, but the "Slope Current" and Atlantic Current have merged.

Between the Atlantic and Labrador Currents there is evidence on both sections of eddy systems of the type and size described by Voorheis, Aagaard and Coachman (1973), although the partially sub-surface nature of the eddy on the northern section is probably a reflection of the somewhat arbitrary choice of reference level.

Geostrophic velocities on the Flemish Cap-Grand Bank section, relative to a 600 m reference level, are shown in Fig. 6; the velocities above the Grand Bank were computed by a modified version of Helland-Hansen's technique (Ellett and Martin, 1973, and Hill, 1971). The reference level of 600 m was chosen by fitting the geostrophic velocity profile between Stations 47 and 48 to the residual currents perpendicular to the section recorded at Station B during the 12 hour 25 min tidal cycle nearest to the time of occupation of the series stations (i.e. the first). The geostrophic current velocities above Flemish Cap and on Grand Bank at Station 43 were similar adjusted, using the residual currents recorded at Stations A and D over the nearest 24 hour 50 min tidal cycle to eliminate the diurnal periodicity apparent over the banks.

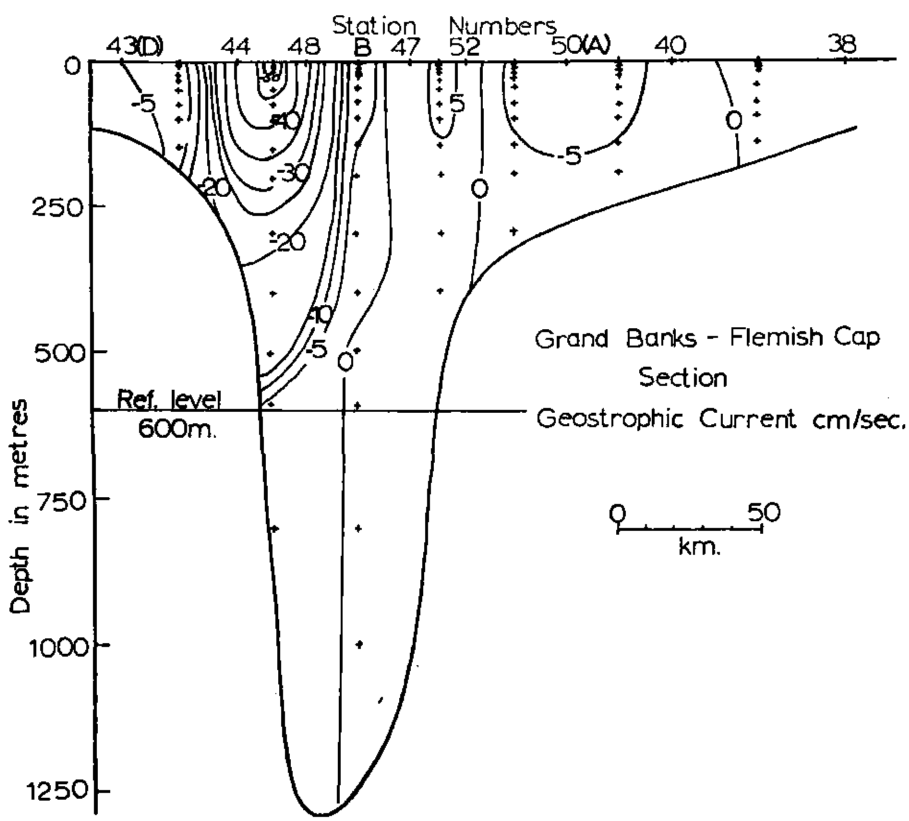


Fig. 6. Geostrophic currents: Grand Bank-Flemish Cap Section.

The corrected geostrophic current velocity profile as given in Fig. 6 includes the residual current components perpendicular to the Flemish Cap section, as measured at the recording current meter stations. It can be seen that the Labrador Current has a maximal velocity of about 55 cm/sec, extends in depth to at least the adopted reference level and appears to be a shelf-edge phenomenon in that it lies against the edge of the Grand Bank itself. The normal clockwise gyre around the Flemish Cap as reported by Kudlo and Burmakin (1972) is seen to be reversed at the time of sampling but it is weak, having a maximum measured mean southerly component velocity of 8.4 cm/sec near the surface. After 21 April, in fact, a relatively steady northwesterly drift of about 3.5 cm/sec, which is more in keeping with Kudlo and Burmakin's report, was calculated from the current meter data recorded at Station A (see Fig. 7).

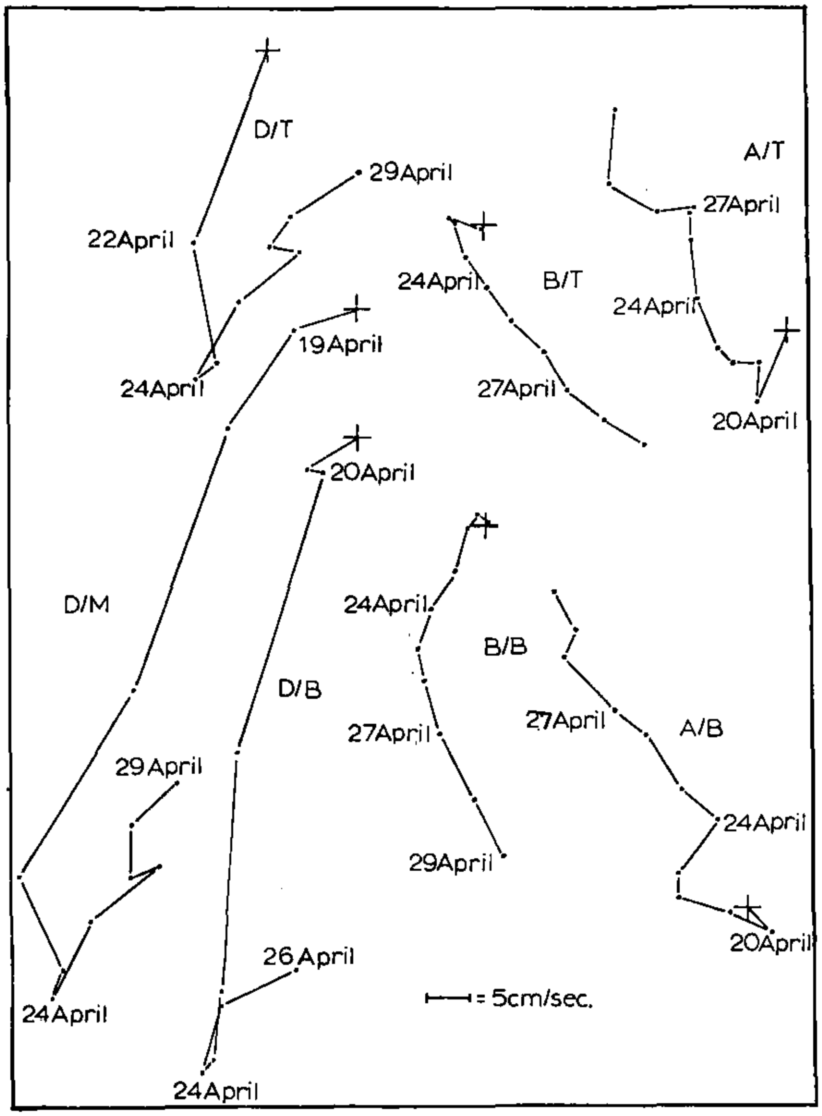


Fig. 7. Twenty-four hour and fifty min. current meter residuals.

Mass transport of the Labrador Current

We may now calculate the mass transport of the Labrador Current across the three sections, and the results are given in Table 2. It is clear from the geostrophic velocity profile at Fig. 5(B) that part of the Labrador Current is to the west of Station 98, which accounts for the lower transport value on the northern section, and suggests that the estimates for the Flemish Cap and southern sections are the more realistic.

Our estimates of transport lie within the range of 1-11 × 10^6 tonnes/sec, derived from the 47 estimates over similar sections across the Labrador Current that have been published by a series of authors since 1965 in the USCG Oceanographic Report Series. More often than not the sections that have been sampled are sections A2 and A3 in USCG nomenclature and most of the estimates lie, in fact, within the range 1-6 × 10^6 tonnes/sec, with an overall mean of 3.6 × 10^6 tonnes/sec. It would appear therefore that the 5.5 × 10^6 tonnes/sec level found in 1972 was rather higher than usual. This accounts for the somewhat lower than normal temperatures previously reported in the current on the Flemish Cap section.

TABLE 2. Mass transport of the Labrador Current, in 10^6 tonnes/sec.

Section	Mass transport
Flemish Cap	5.32
Northern	2.92
Southern	5.60

Variability of tidal streams and residual drift on the Flemish Cap section

Wolford (1966) launched a number of parachute drogues in the Labrador Current at a time when he estimated the mass transport to be 5.4 × 10^6 tonnes/sec. The drogue velocities in the core of the Labrador Current over deep water varied from 36 to 81 cm/sec, which agreed reasonably well with the geostrophic velocities calculated from hydrographic sections worked during the same cruise although, as might be expected, the agreement was less good over the shallow banks. Thus our mean near-surface geostrophic velocities of 55, 30 and 33 cm/sec on the Flemish Cap, northern and southern sections respectively seem reasonable, bearing in mind the mass transports which we measured.

However, it is clear from Fig. 7, which shows the twenty-four hour and fifty min. residuals at each of the current meter positions (see Fig. 1) that there is a considerable variability in both velocity and direction about the mean flow at each of the three points on the Flemish Cap section at which observations were made, with very great and abrupt changes of regime occurring on the Grand Bank itself. At Station D, for example, which lies to the west of the core of the Labrador Current, an essentially south-going regime of 18 cm/sec/day at all sampling depths comes to an end suddenly on 24 April and is replaced by northeasterly advective drift of the order of 6 cm/sec/day. This change in overall character is paralleled by a change in tidal stream character. In the period 21-23 April, the direction of drift remains fairly steady at about 200°, but a diurnal periodicity can be seen in the velocity record. Maximum velocities recorded fall in 10 cm/sec stages from 40 cm/sec on 21 April to 20 cm/sec on 23 April. After 23 April directions rotate round the compass in 24 hour periods, with stream velocity maxima occurring at 20 cm/sec. Then on 28 April steady drift in the 0-100 direction zone with a diurnal velocity regime becomes established. Such transient tidal stream characters are presumably the result of changes in residual drift patterns being imposed on a weak diurnal tidal regime. However, no such radical changes are found in the temperatures recorded in the middle and near the bottom of the water column at this station. In both cases the water temperatures lie between -0.6 and -1.6°C throughout the period. This suggests that the gross variability found in the residual drift regime was the result either of large-scale changes in the advective drift of the waters to the west of the core of the Labrador Current, or of a change in the position of the core itself.

Some evidence in favour of the idea that the position of the core of the Labrador Current actually changed is provided by the temperature record of the top current meter (286 m) at Station B; here, temperatures of 4°C occurred until early on 26 April, when they fell in 30 min. to 1.75°C and for the next two days varied in the range of 1.75° to

3°C before returning to the 3-4°C level on 28 April, where they remained until the meter was recovered on 1 May. Reference to Fig. 2(A) shows that these changes would be made possible by an easterly translation, of some 40 km, of the core of the Labrador Current, followed by a return to the position at which we had observed it on 17-18 April. Although the rapid temperature change occurred two days later than the direction change at Station D, it seems that the two processes may be related.

There is in fact no drastic change in the residual drift regime at Station B, at any time, similar to that found at Station D on 24 April. The record at 286 m depth shows that after 3 days of small and variable residual drift a steady 5 cm/sec southeasterly drift developes on 23 April and continues for the rest of the time the station was maintained. At 688 m depth a southwesterly trend begins on 22 April and lasts until 26 April, when a southeasterly regime becomes established. Residual velocities at this depth lie in the range 2-7 cm/sec/day. Tidal streams at both levels are very poorly developed. At 286 m depth there is diurnal periodicity throughout the velocity record and also in the first half of the direction record. After 0600 hours on 26 April, however, all recorded directions lie in the zone 150°±50°, with very little discernible periodicity. At 688 m depth the recorded velocities suggest the presence of a semi-diurnal pattern is more pronounced. The recorded directions show little periodicity, but do change in general character at times. In the period 21-23 April, for example, directions lie between 250° and 050°, but during 23-26 April steady drift at 200°±50° is found and is replaced for the last five days of the record by drift in the zone 150°±50°.

Finally, the temperature and current meter data recorded at Station A suggest that a third distinct residual drift regime occurs at the eastern end of the Flemish Cap section.' It has already been noted that previous workers in the region have suggested that normally there is clockwise gyre round the Flemish Cap itself, and the essentially northwest-going drift (mean daily velocity (3.5 cm/sec) found in both records at this station on and after 21 April provides support for this view. Further corroboration is supplied by the fact that the temperatures recorded at the near-bed instrument lie in the range 3.9° to 4.3°C and this is quite different from those found at either of the other two anchored stations in this section. The typical south-going component of drift found in both records on 20 April is presumably a consequence of the north-westerly gale that blew for most of the day and reached 40 knots at times in the vicinity of Station A.

Throughout the data collected at this station there is a clear diurnal periodicity, the tidal streams rotating through 360° in 24 hours for most of the time, and the velocities, especially at the near-bottom meter, forming distinct sinusoidal waves. Peak velocities are attained at both levels during the period 19-23 April, with absolute maxima being 46 cm/sec at the near bottom meter and 34 cm/sec in the near-surface layer. After 23 April peak levels do not exceed 30 and 20 cm/sec in the near-bed and near-surface levels respectively.

The temperature-salinity curve of the Slope Water Current

It has been stated earlier that the north-going stream found to the west of the main Atlantic Current, and centered on Station 62 on the southern section, might be thought to be Mann's "Slope Water Current" although, as we have shown, it is deficient in mass flow. However, an examination of the temperature-salinity curves, a selection of which is given in Fig. 8, shows that this is not completely so. The temperature-salinity curve representing Stations 70 and 72 follows closely the expected curve for Atlantic Current water (and indeed Gulf Stream water) as given by previous workers, e.g. the 20-year mean produced by Morgan (1969). Station 57 is representative of Labrador Current water and the remaining stations are clearly mixtures of these two water masses, with a steadily increasing percentage of Atlantic Current water as the stations proceed to the east, i.e. Stations 58, 62 and 68. Thus as Station 62, we have a well-mixed layer down to 150 m, with a mixture of Labrador Current and Atlantic Current water beneath this depth which is almost the same percentage mixture as that at Station 68. Both of these may properly be called Slope Current water, since the Slope Current originates further south as a mixture of these two currents, and clearly the stream centered on Station 62 is not of itself Mann's "Slope Current", since this extends into, and indeed is part of, the main northerly transport of water between Stations 68 and 70. In fact it is suggested that the mixing process has already begun south of this section and that we are examining part of this mixing process. This would account for the low transport of the "Slope Current: centered on Station 62, and we should properly take the region between Stations 62 and 68, including the southerly stream, as "Slope Current". It would seem reasonable in fact to think of advective movements in this area as forming part of an eddy produced by the volocity shear between the 40 and 13 cm/sec streams indicated on Fig. 5.

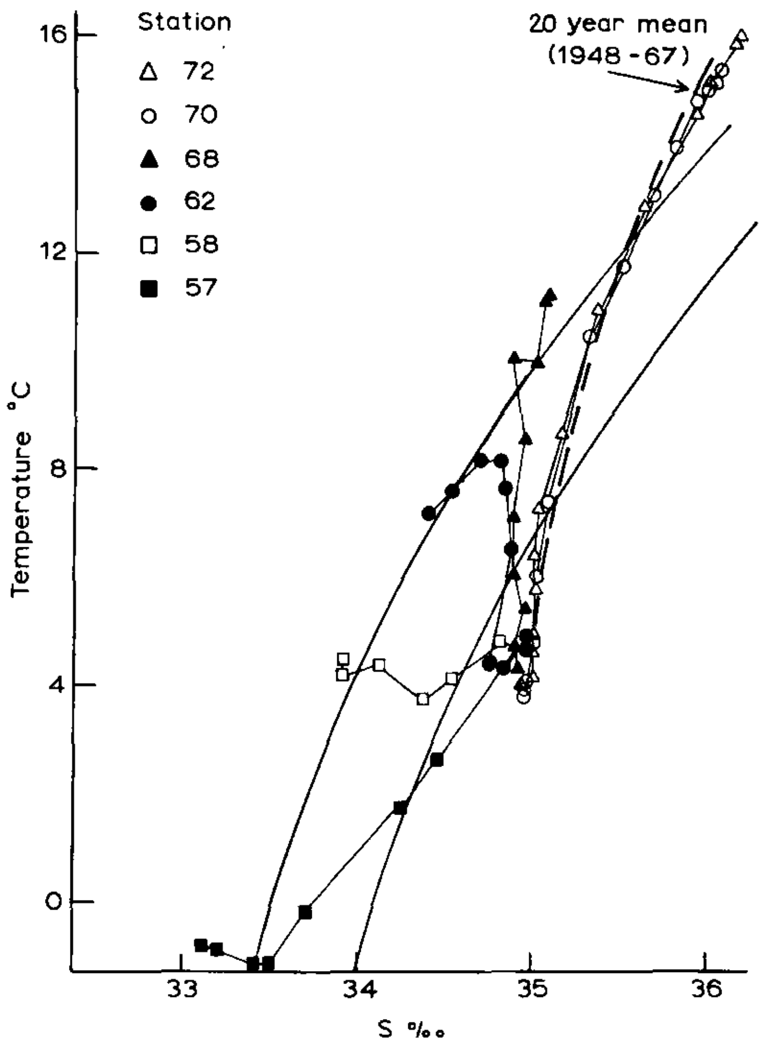


Fig. 8. Temperature-salinity diagram, southern section.

Oxygen/sigma-*t* curves from April-May 1972

It is of interest to consider the oxygen/sigma-*t* curves as first used by Worthington (1962) to distinguish the highly-oxygenated water of the Atlantic Current. Worthington showed that the O_2-σ_t relationship for waters in his southern gyre conformed very closely to the curve established by Richards and Redfield (1955) for the Sargasso Sea, whereas all the O_2-σ_t curves drawn for stations in the area of his northern gyre (Atlantic Current) lay above the Richards and Redfield curve in a similar fashion to those of Stations 68 and 70 on Fig. 9. These curves, it should be noted, together with the others on the figure come from selected stations of our southern section (Stations 56-76).

Comparison of the curves for Stations 58 and 62 with those of Stations 68 and 70 shows that the oxygen content at a given density surface decreases consistently eastwards, particularly in the surface layers at densities less than σ_t = 27.2. When the remaining stations are plotted this trend is still apparent, though the decrease is not as regular as indicated by the selected stations. This is to be expected, bearing in mind the temperature-salinity relationship, since we are getting a smaller percentage of the more highly-oxygenated Labrador Current water. If this were the only source of highly-oxygenated water we would expect this decreasing trend towards the east to continue, but the curve for Station 78 on Fig. 9 shows a reversal of the trend in that the oxygen content increases again at depths less than 600 m (σ_t = 27.16) and in fact the oxygen values are greater than 4.94 *ml/l* down to this depth. This feature is clearly apparent on Fig. 4(C). A similar unexpected high

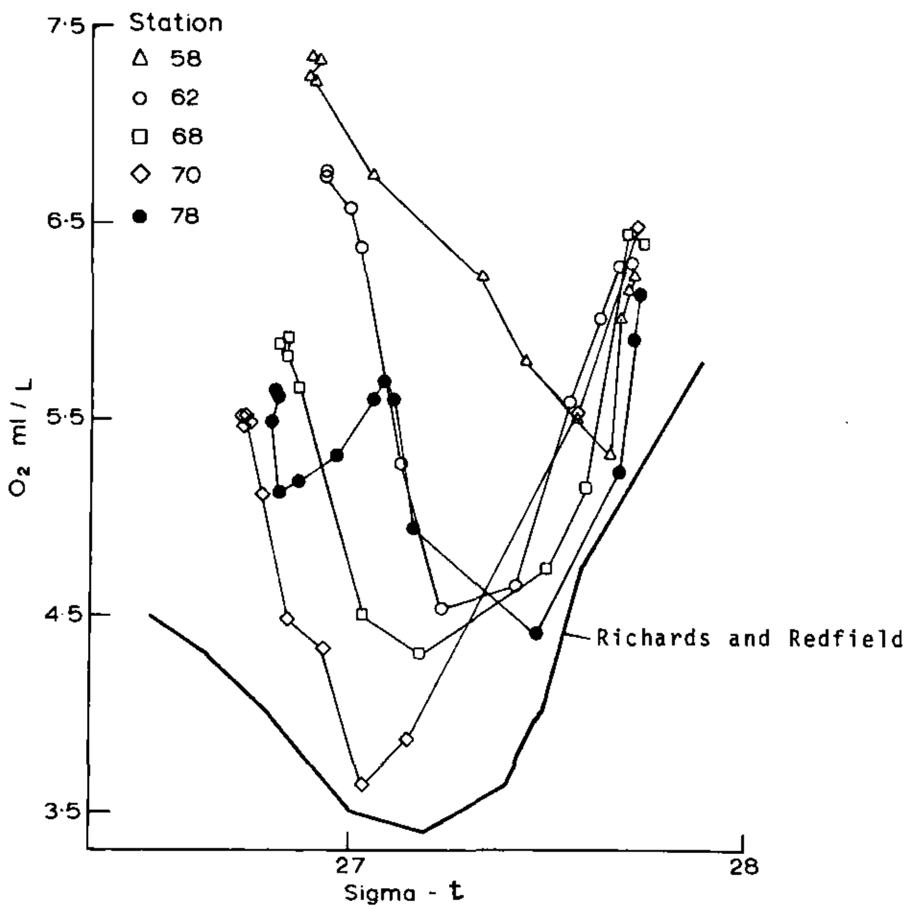


Fig. 9. Oxygen/sigma-*t* diagram.

oxygen content to a depth of 500 m occurs on the northern Section at Station 84, but the decreasing trend easterly is less marked than on the southern section.

It is therefore possible that at the easterly end of our survey we have entered the gyre which Mann believes is the source of the high oxygen values in the Atlantic Current.

Acknowledgements

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Circulation Pattern in the Newfoundland Ridge Area, 1972

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INTRODUCTION

The study of the Gulf Stream has long been of interest to the scientist and to the general public living in the maritime region of the North Atlantic. The major volume of the work done on the Gulf Stream has been carried out on the eastern seaboard of the USA, with very little being done in the large area surrounding the Grand Banks.

One of the earlier pictures of the general circulation of the North Atlantic was produced by Iselin in 1936 (Fig. 1). This shows the Gulf Stream flowing along the shores

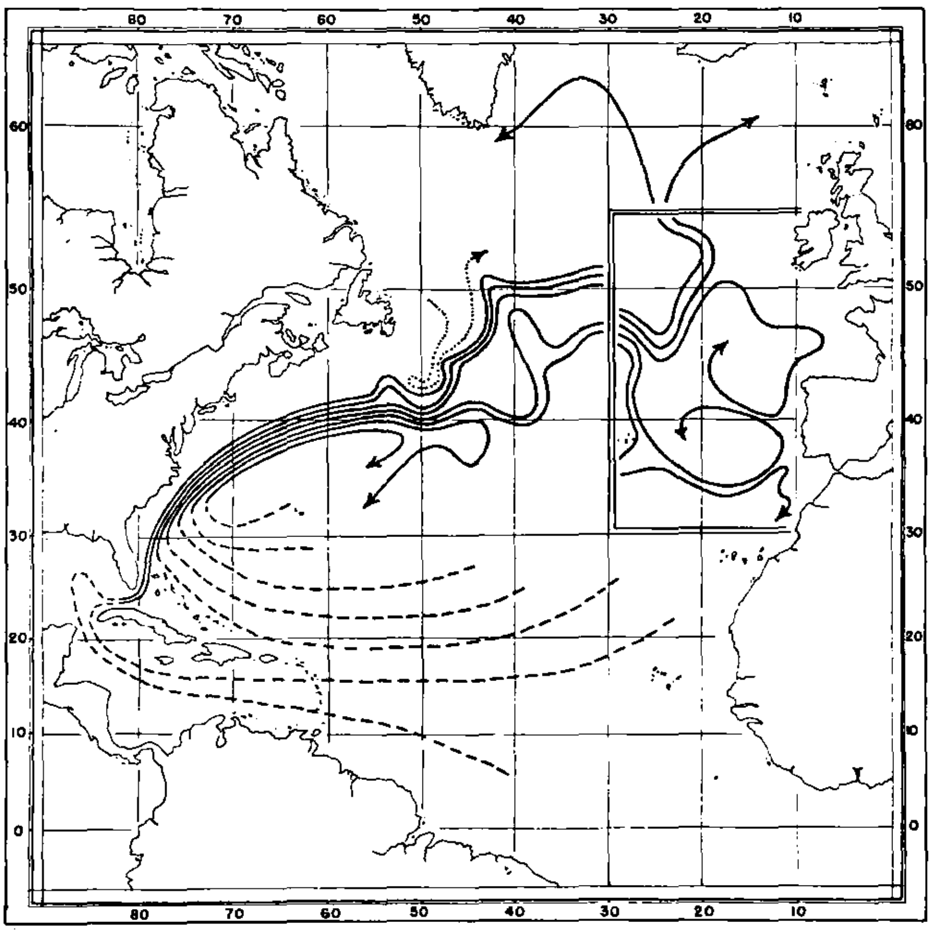

Fig. 1. Iselin's chart showing the Gulf Stream system in the western half of the ocean. Each streamline represents the transport of approximately 12×10^6 m^3/sec.

of the USA, leaving the shelf around Cape Hatteras, then meandering eastward along 40° until around 50°W. At this point the stream splits with the northern branch to form part of the North Atlantic Current and the southern branch bending back to the south.

In following years a number of scientists presented circulation patterns which grew in detail; however, the basic flow pattern remained similar to Iselin's. The Gulf Stream grew in complexity, adding counter currents, eddies, etc., and the Slope Water Current appeared. Slope Water is a mixture of coastal water and Gulf Stream water formed and found between the Continental Shelf and the Gulf Stream. It flows eastward along the southern part of the Grand Banks, then northward as the Slope Water Current before joining the northern branch of the Gulf Stream to form the Atlantic Current.

In 1962, Worthington (Fig. 2) proposed replacing the model of a splitting Gulf Stream with a two gyre system with virtually no interchange between them. This picture is quite different from all the previous ones, and his circulation pattern was based on the fact that the oxygen values at depth were higher in the Atlantic Current than in the Gulf Stream. Since the oxygen content could neither be changed by contact with the atmosphere or by direct mixing of different masses of water, Worthington concluded that there must be different water masses north and south of the Newfoundland Ridge.

In 1967, Mann proposed a somewhat different picture than Worthington. However, it had some similarities with the earlier ones (Fig. 3). He shows the Gulf Stream splitting, but also shows an eddy in the Newfoundland Basin, and the Slope Water flowing across the ridge northward to join up with the northern branch of the Gulf Stream.

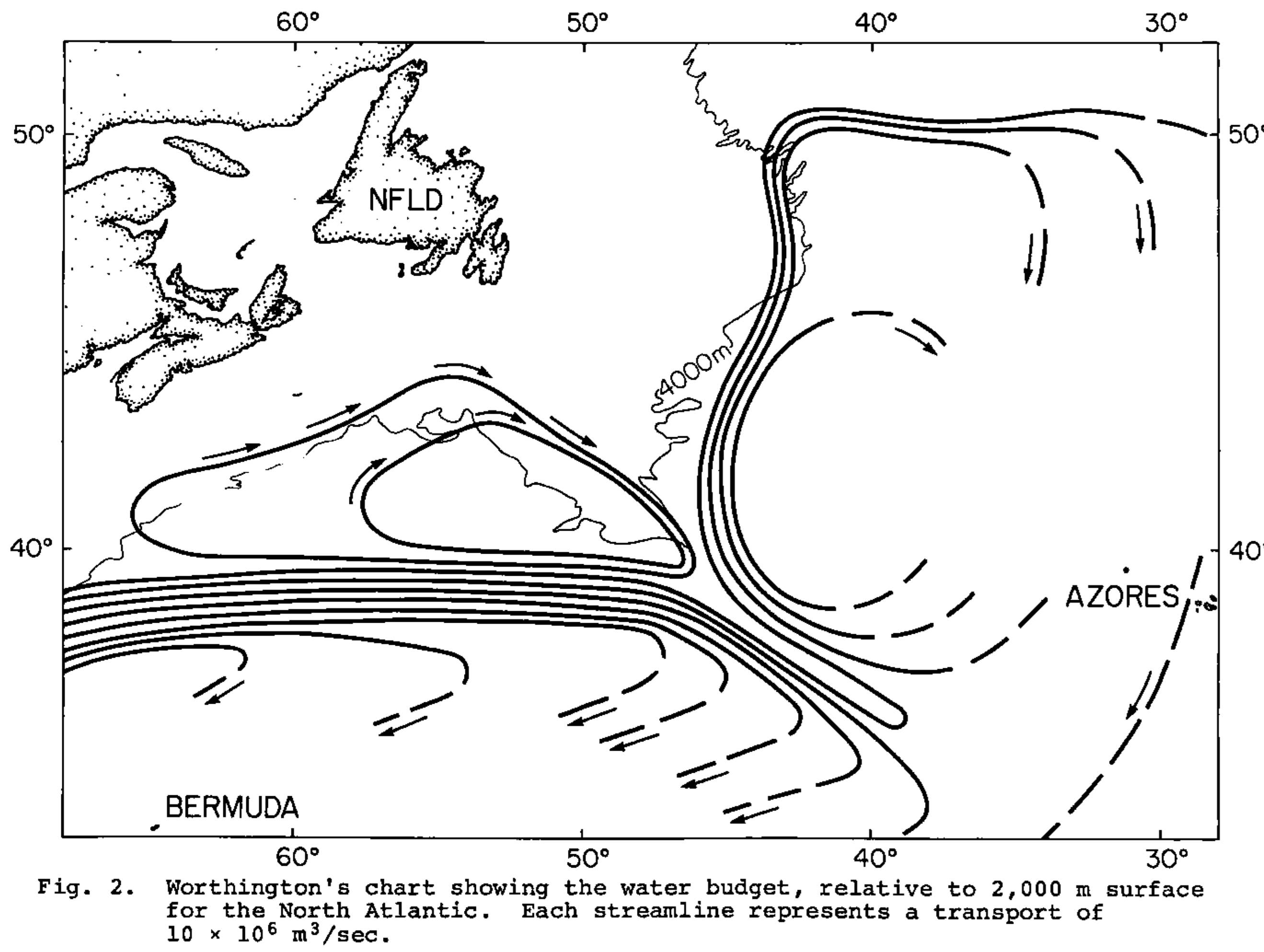

Fig. 2. Worthington's chart showing the water budget, relative to 2,000 m surface for the North Atlantic. Each streamline represents a transport of 10×10^6 m^3/sec.

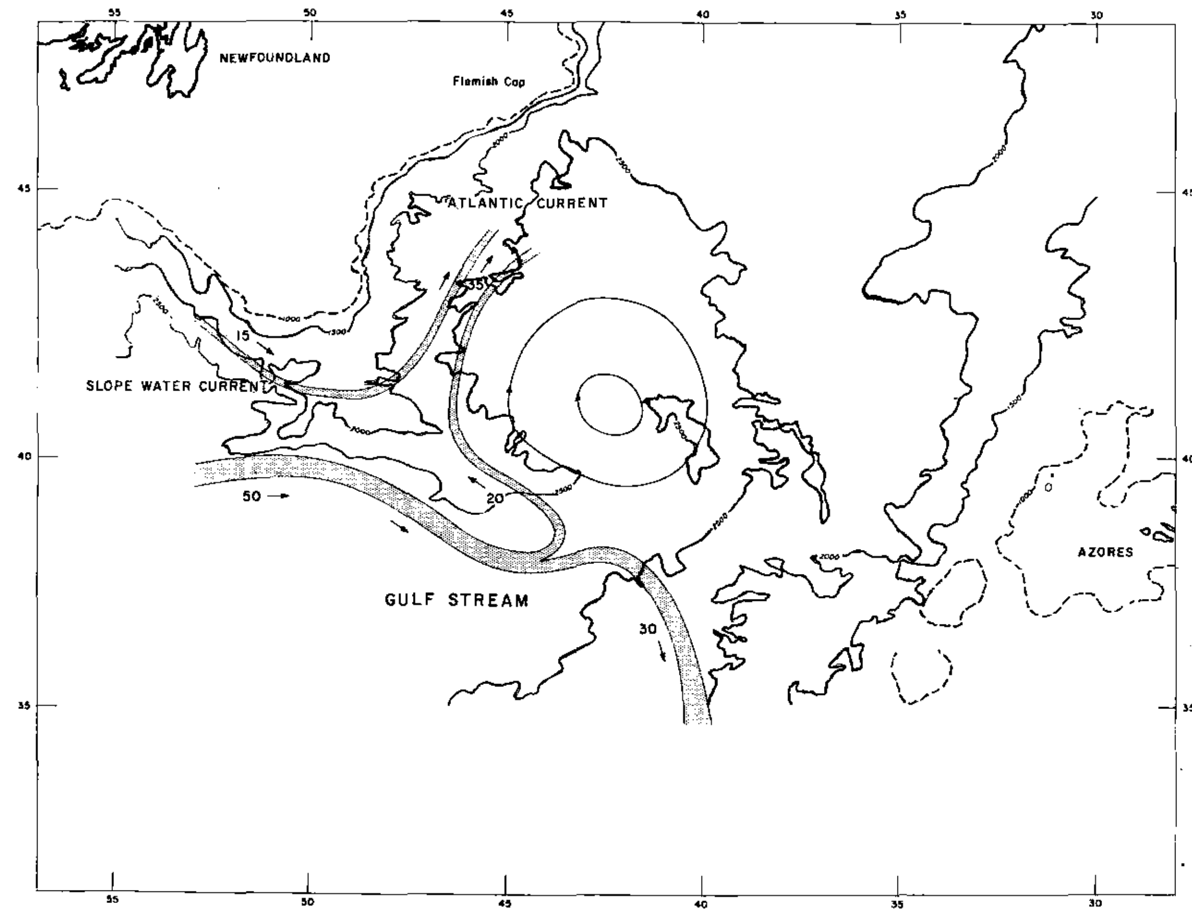

Fig. 3. Mann's current system southeast of the Grand Banks. Nominal transports are in 10^6 m^3/sec.

METHOD

In 1969, the Bedford Institute of Oceanography started a program to develop current meter moorings for the deep ocean. The first field trials were carried out in 1970 just south of the Tail of the Banks (Fig. 4). Three current meter moorings were deployed for a period of about 10 days during which the temperature and salinity along the line was sampled several times. In 1971, three more moorings were placed in much the same area (Fig. 5). Two of these moorings gave records for about 5 weeks and the third for two weeks. These show that the position of the Gulf Stream as it crosses 50°W shifts its position quite considerably over a few days. This shift is probably due to east-west movement of meanders of the stream rather than the north-south shift of the axis itself. This is supported by the current meter data which in general indicate mean currents beneath the Gulf Stream with a considerably north-south component of velocity.

In 1972, a comprehensive survey off the Tail of the Grand Banks area was carried out by three ships, namely the R/V *Cirolana*, Fisheries Laboratory, Lowestoft; the R/V *Chain* from Woods Hole Oceanographic Institution and the R/V *Hudson* from the Bedford Institute of Oceanography.

RESULTS

This paper describes some of the observations of the *Chain* and *Hudson*. The first phase was to place two lines of current meter moorings totaling 22 moorings, then occupying a grid of hydrographic stations in the area partially bounded by the moorings (Fig. 6). The general circulation pattern can be derived by examining the temperature

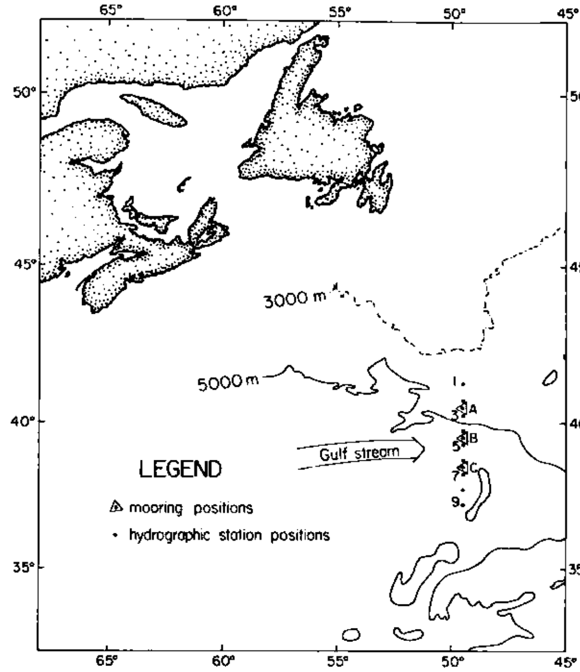

Fig. 4. Current meter moorings and bottle position for cruise 70023, CSS *Dawson*, 1970.

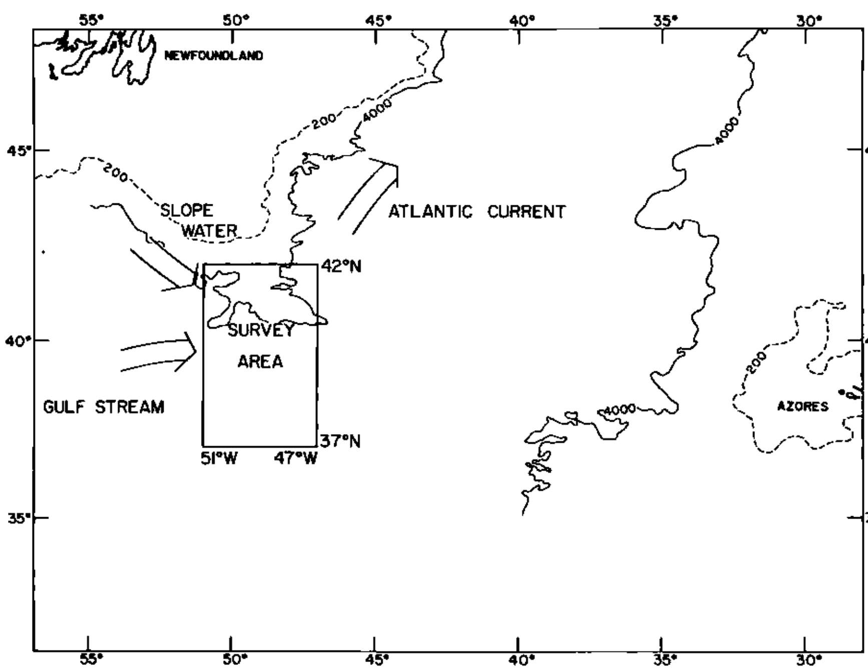

Fig. 5. Survey area for cruise 71-016, CSS *Dawson*, 1971.

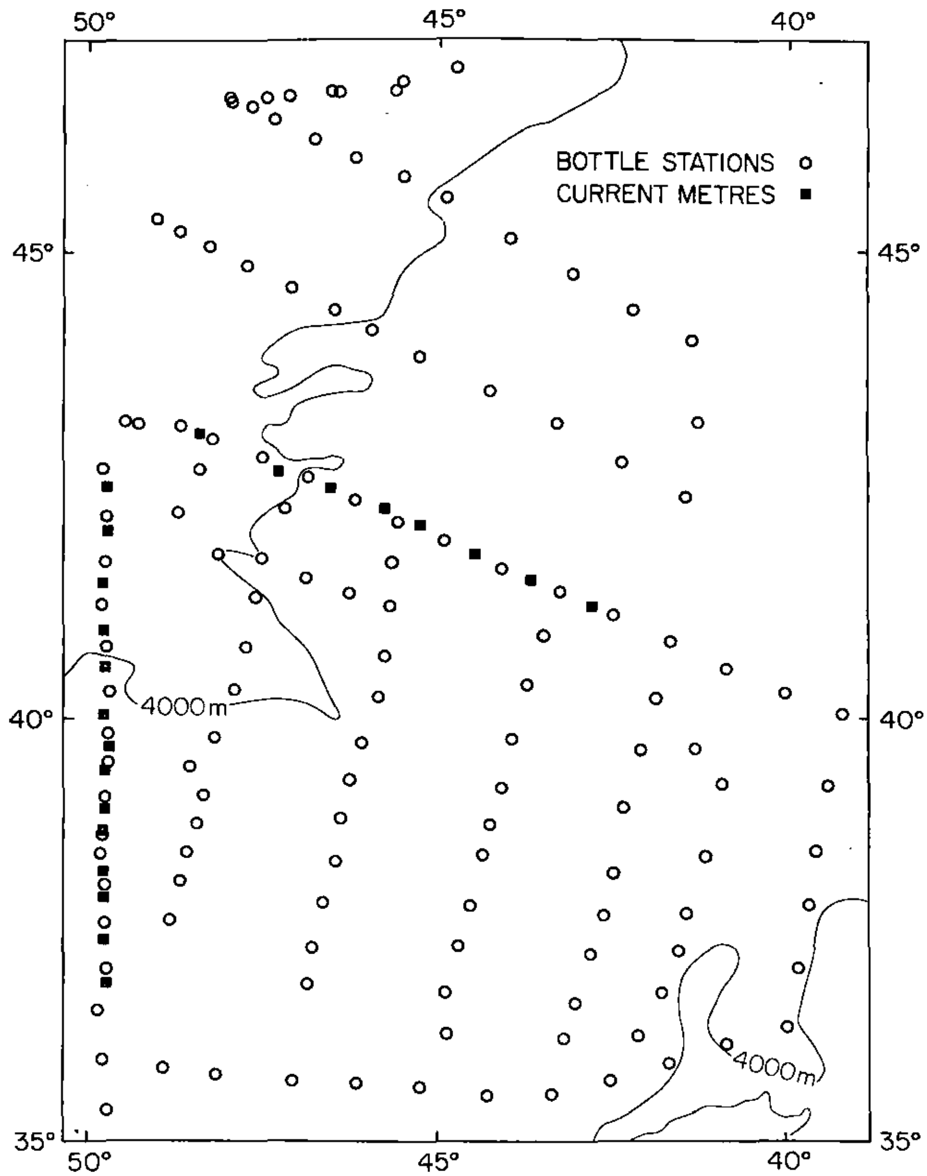

Fig. 6. Current meter mooring and bottle position for R/V *Hudson* and R/V *Chain* 1972.

and dynamic fields. The potential temperature field (Fig. 7) taken along 40°45'W from 5 to 9 May shows the cold water of the Labrador Current to the north, then a region of a mixture of water types followed by very strong gradients in the temperature field which marks the Gulf Stream and the Slope Water Current. The remainder of the line shows some smaller scale features, however, nothing that shows strong coherence with the other sections in the survey.

The northern line (Fig. 8) shows the cold Labrador water in the west, a mixing zone, then a region of strong gradient which is the Atlantic Current and the eddy located in the Newfoundland Basin.

Now examining the depth of the 10°C isotherm (Fig. 9) over the survey area, the Gulf Stream and the Slope Water Current are seen entering at 41°N where the depth changes from the surface to 800 m. As the flow encounters the Southeast Newfoundland Ridge, the offshore (600-800 m) position swings to the south while the remainder swings across the ridge to the north. Additional splitting occurs with the 600 m contour returning northward to join the northward flowing water, the 700 m contour goes to the east and the 800 m contour continues southward into the Sargasso Sea. An anticyclonic gyre is quite evident in the Newfoundland Basin where the 10° isotherm dips to 800 m. Additional supporting evidence for this general circulation pattern is given by the surface topography (Fig. 10). The surface topography relative to zero current at 2,000 dbars

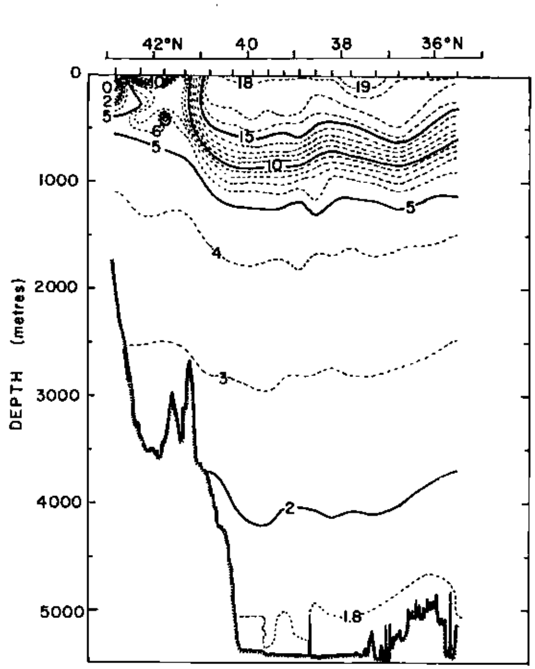

Fig. 7. Potential temperature section along 49°45'W as observed by R/V *Hudson* from 5 to 9 May.

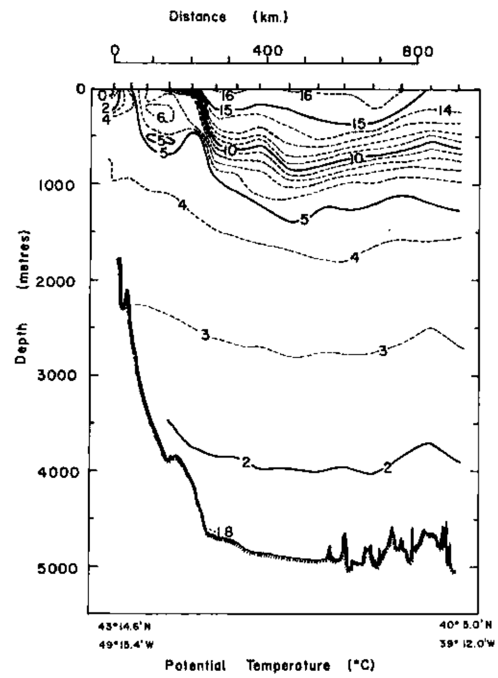

Fig. 8. Potential temperature section east of the Grand Banks as observed by R/V *Chain* and R/V *Hudson*.

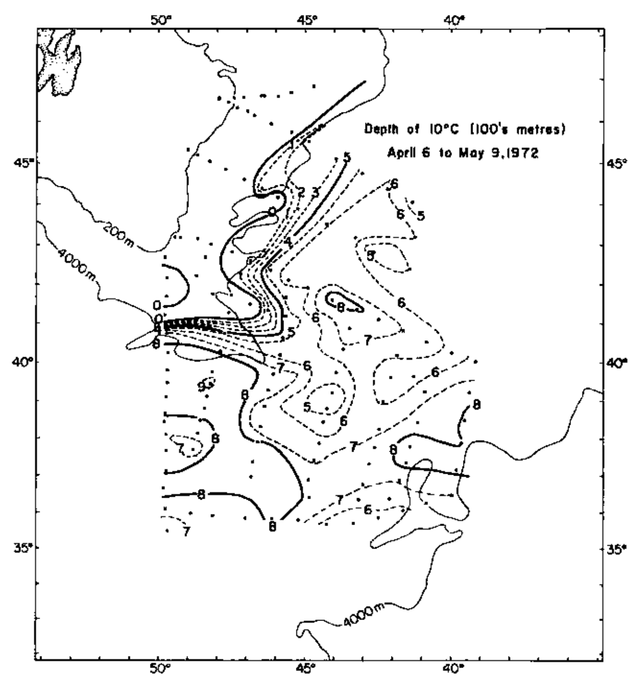

Fig. 9. Chart showing the depth of the 10°C isotherm as observed from 6 April to 9 May, 1972. The depths are in 100's of metres.

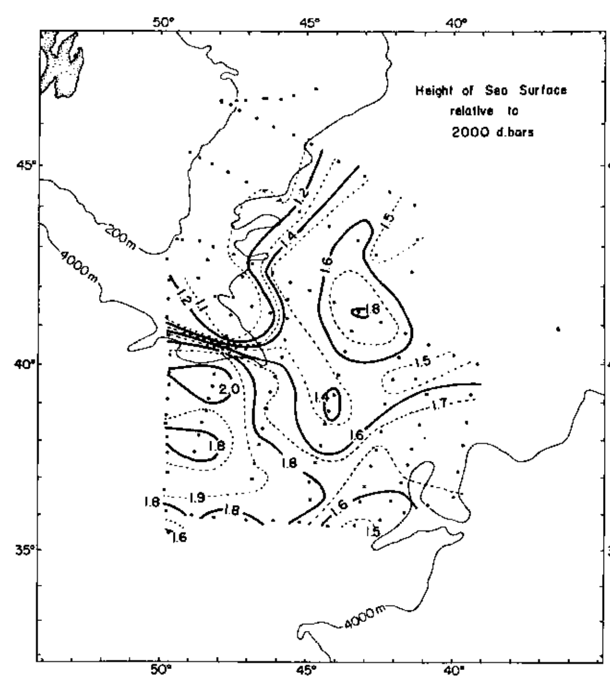

Fig. 10. Chart showing the height of the sea surface relative to zero at 2,000 dbars. This was observed from 6 April to 9 May, 1972. The height is displayed in metres.

shows the same basic flow pattern as the depth of the 10° isotherm. The picture is consistent with Mann's model. A noteworthy feature is the low pressure trough that runs to the northeast, indicating that a branch of the Gulf Stream flows through the eastern boundry of the survey area rather than all turning to the south around 40°W as had been previously observed.

THE TEMPERATURE FIELD

Now, that a general circulation pattern for the area has been arrived at, a closer examination of the temperature field at various scales may be interesting.

The temperature field at 50 m (Fig. 11) as recorded by the bottle stations shows a trough of cold water running southeast of the Tail of the Banks. This trough is highly pronounced due to the temperature of 0.37°C which was recorded at Station 1229 by *Chain*. In order to obtain a better understanding of the splitting of the Gulf Stream mechanism, *Hudson* surveyed the region of the trough using 800 m XBT's (Fig. 12). XBT's were taken every 10 to 20 km apart along the lines which themselves were separated by about 30 km. Again looking at the 50 m temperature field, it shows much more detail. The cold trough now extends out to 45°W. Comparing this data with the temperature field obtained from the bottles it is evident that the cold trough and the eddy in the Newfoundland basin were moving southward. This was supported by the current meter data from the line north of the Newfoundland Ridge.

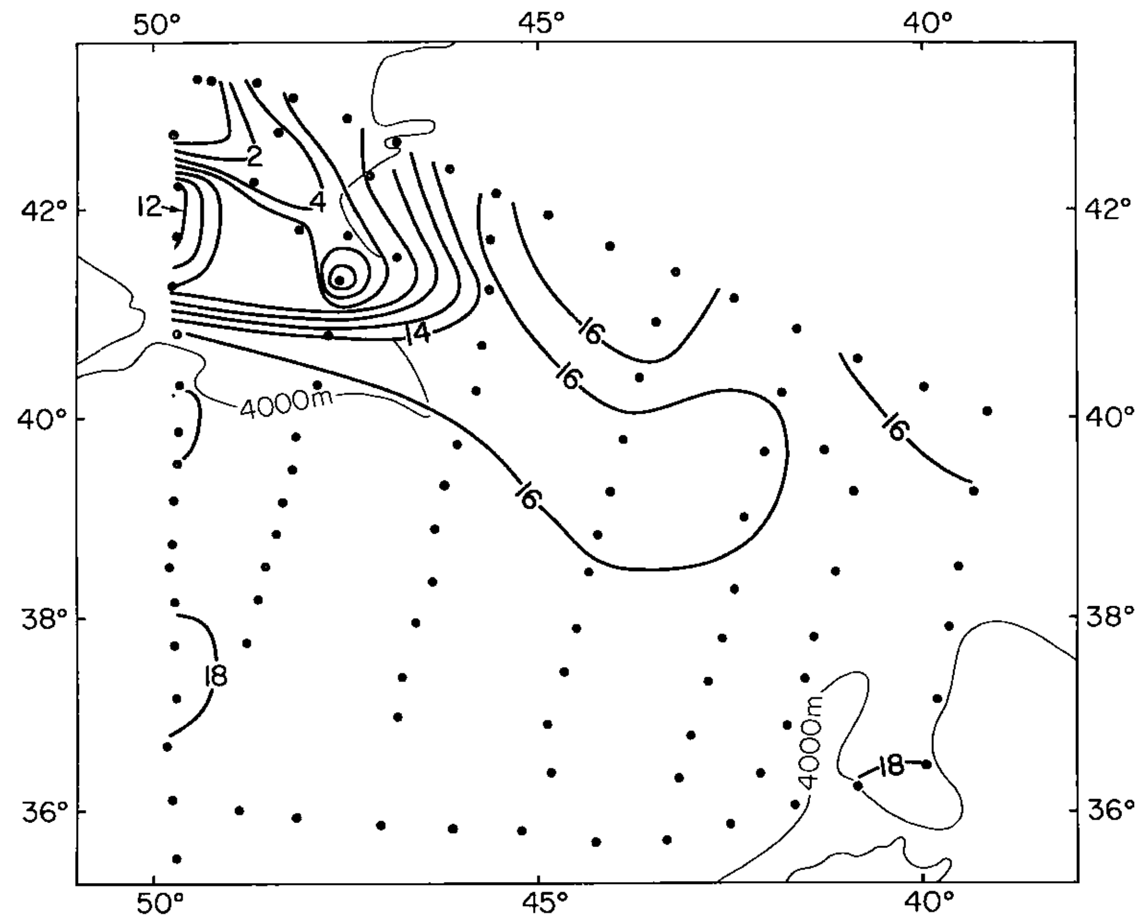

Fig. 11. Chart showing the temperature (°C) at a depth of 50 m as obtained from the bottle data of R/V *Hudson* and R/V *Chain* from 6 April to 9 May, 1972.

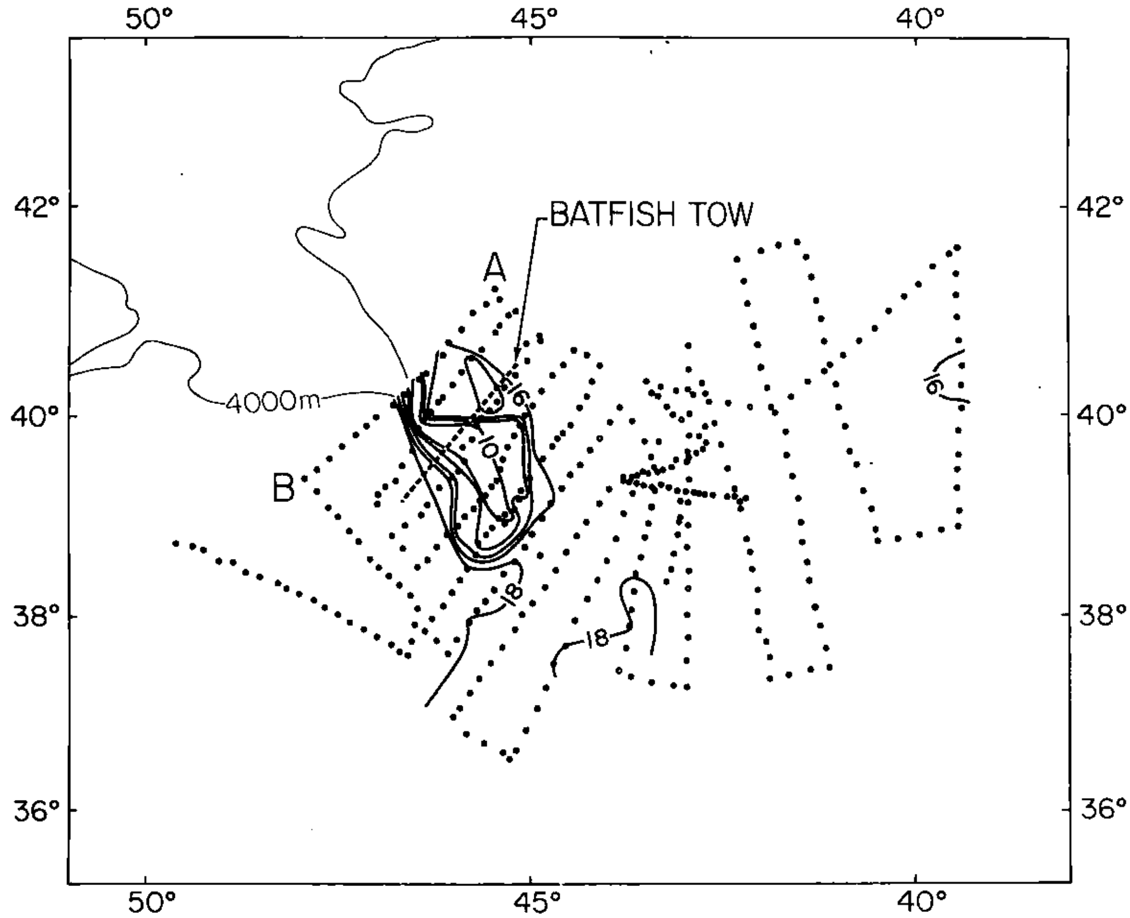

Fig. 12. Chart showing the temperature (°C) at a depth of 50 m as obtained from the XBT's during 18 May to 1 June, 1972.

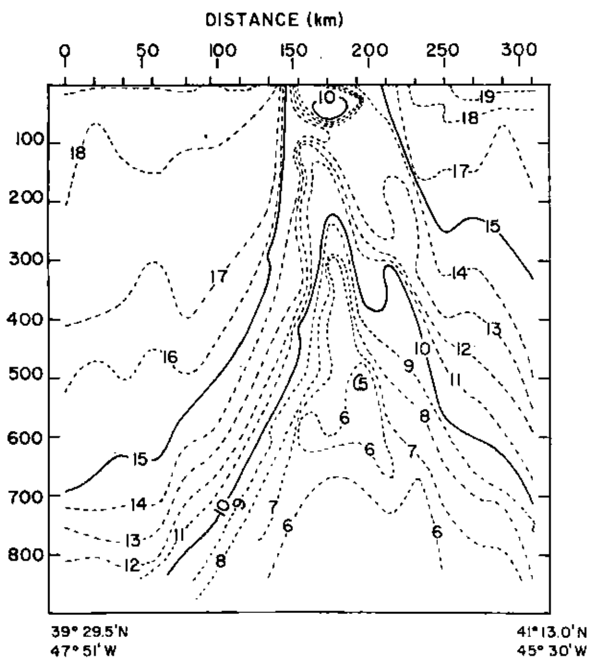

Fig. 13. Temperature section obtained from the XBT data as observed on 18 May, 1972.

The gradients found by the XBT's are very sharp (Fig. 13). The cold water dome shows a scale of 100 km or more whereas there are numerous features with scales of 10 to 30 kms. It is important to keep in mind that the conventional bottle survey would have station separation varying from 35 to 80 kms and even as high as 120 kms and hence such features were likely to be missed.

During this same phase on *Hudson*, the batfish was towed for a number of hours. A part of the temperature field as recorded crossing the cold ridge, about 50 km southeast of the XBT Section 'AA' is shown in Fig. 14. The batfish is porpoising up and down in about 4 kms, therefore the sampling is about 10 times as dense as the XBT's were and 20 to 30 times as dense as the bottles.

The isotherms show about the same overall dome shape, except now there is a variety of features of even smaller scales present. It is worth noting that most features persist over several samplings hence the batfish sampling is fine enough to resolve most of them. There are present several very sharp gradients. For example, on the south side of

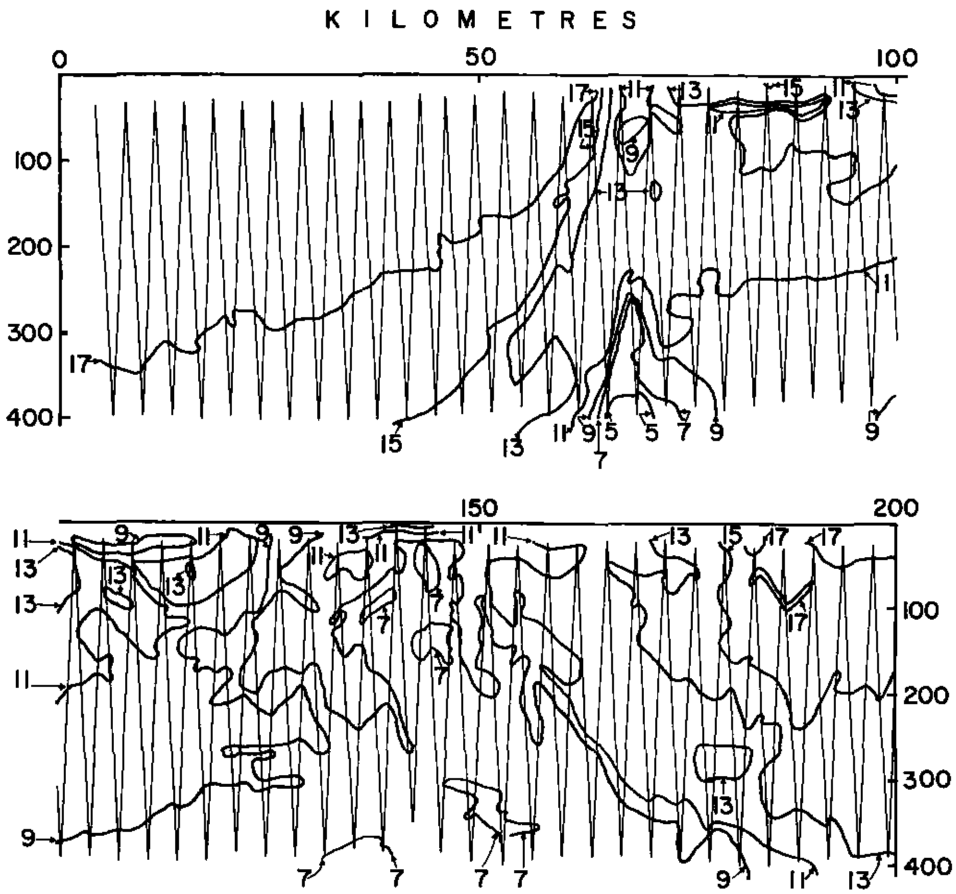

Fig. 14. Temperature section obtained by towing Batfish as observed on 21 May, 1972.

the dome, the 13°C isotherm goes from 400 m up to 20 m in about 10 kms. In spite of such a noisy temperature signal when the salinity is taken into account, the density through this feature is quite smooth.

Gulf Stream and Atlantic Current Velocities and Transports

Another objective of the project was to obtain estimates of the velocity and transports of the Gulf Stream and of the Atlantic Current. The bottle stations data were used to calculate the geostrophic shears for all adjacent station pairs. The shears were matched to the 24 hr average velocity as obtained from the current meters for that 24 hr period during which that pair of stations were occupied. Where currents were measured at more than one level, the reference velocity was chosen so that the geostrophic velocity profile best matched the current meter values at all levels. Missing current meters were simulated by linear interpolation between adjacent meters. Figure 15 gives the velocity field across 49°45'W. In the north we see the Gulf Stream with a maximum surface speed of 90 cm/sec to the east and 10 cm/sec isotach extending to nearly 3,000 m up on the Continental Slope. To the south of this, there are two fairly strong flows to the west and to the east which extend to the same sort of depths as does the Gulf Stream, and in both cases the flow accelerates again close to the bottom. This structure may be the Gulf Stream meandering in form of an S up 50°W or the edge of a Gulf Stream eddy.

Figure 16 gives the currents across the northern line. Tucked beside the Continental Slope we see the Atlantic Current with surface speed of 50 cm/sec and the 10 cm/sec isotach deepening to 2,500 m. Offshore of this is the northward then southward flow of the anticyclonic eddy with surface speeds of about 20 cm/sec.

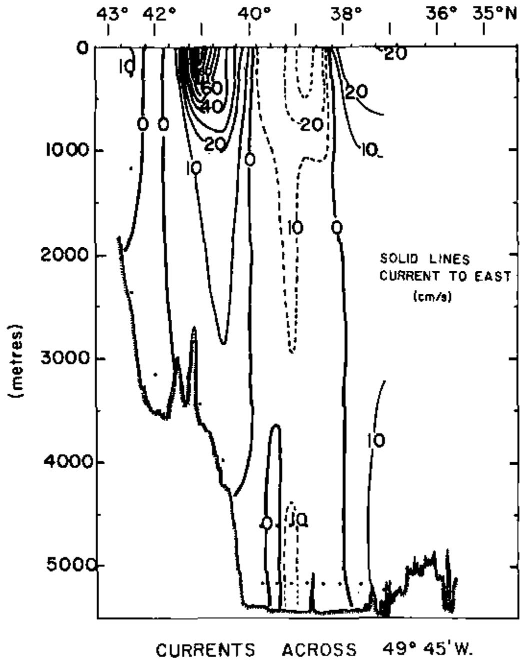

Fig. 15. Current section along 49°45'W as observed by R/V *Hudson*. Solid lines represents current to the east, dashed lines represent current to west. The current is in cm/sec. and based on the current meter observations (current meter positions are indicated by dots).

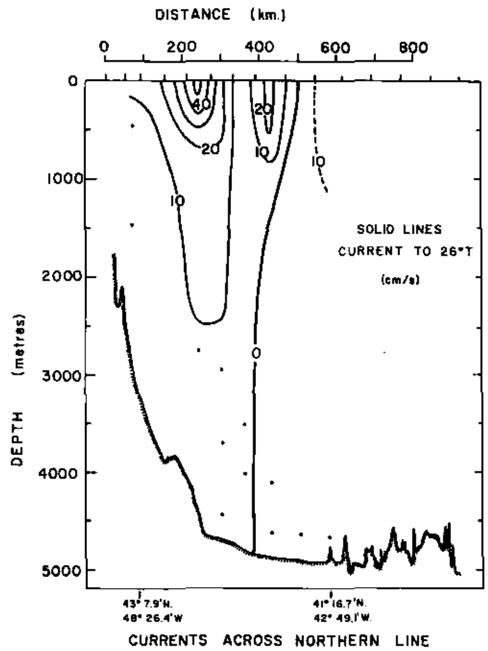

Fig. 16. Current section east of the Grand Banks as observed by R/V *Chain*. Solid lines represent current northward (26°T). Current is in cm/sec. and is based on current meter observations (current meter positions are indicated by dots).

The transports of the Gulf Stream and the Atlantic Current are given in Table 1 in units of 10^6 m^3/sec. The 50°W line was occupied three times; two estimates of the transports are given here. Since the Slope Water Current appears to have coalleased with the

TABLE 1. Summary of transports for the Gulf Stream, Slope Water and Atlantic Current (transports in m^3/sec × 10^6).

	Total current meters	Upper 2,000 m: Current meters	Upper 2,000 m: 2,000 dbars
Gulf Stream and	114	87	60
Slope Water Current	100	87	53
			50+15 (Mann, 1967)
	144	79	41 (Gulf Stream only, 1970)
	119	75	45 (Gulf Stream only, 1970)
Atlantic Current	123(61)	93(26)	49(8)
plus	127(55)	88(26)	50(8)
Anticyclonic Gyre	112(12)	76(4)	44(9)
			35 (Mann, 1967)

Gulf Stream it was not possible to separate their transports. We see though that the transports over the whole water column are somewhat less in 1972 than were measured in 1970 along 50°W. There is much less difference between the 2 years if one looks only at the transport in the upper 2,000 m referred to the current meters and virtually no difference if one looks at the transport relative to 2,000 dbars substracting an estimated 15×10^6 m^3/sec as being the Slope Water Current contribution. In 1970 the Gulf Stream was found crossing 50°W at 38.5°N in a depth of 5,200 m and the 10 cm/sec isotach appeared to extend to the bottom. However, this year, the Gulf Stream is up on the Continental Slope in 4,000 m of water. The differences are within the accuracy of the measurements which in 1970 was estimated as being 50×10^6 m^3/sec.

The Atlantic Current transports have not been separated from the transports of the anticyclonic gyre; however, the southward transport across the section by the return portion of the gyre is given in brackets. By subtracting these two numbers we find that over the whole water column the Atlantic Current transports $60 - 100 \times 10^6$ m^3/sec. Referred to 2,000 dbars, our measurements are the same or a little larger than the estimates of Mann.

In conclusion the 1972 data seems to confirm the model proposed by Mann. In particular the data details the very striking low pressure trough overlying the Southeast Newfoundland Ridge, then extending to the northeast. The data is also in agreement with that reported by Clarke and Reiniger at 50°W in 1970 and suggests with it that the Gulf Stream transports ceases to increase east of 65°W.

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Circulation of Waters in the ICNAF Area in April-June 1972 and 1973

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Introduction

In April-June 1972-73 R/V *Protsion* conducted hydrological surveys in the Newfoundland area. Hydrological observations were also made on some standard sections during the eighth and eleventh cruises of R/V *Perseus III*. Treatment of the data obtained by the dynamic method made it possible to consider some aspects of the circulation of waters in the area investigated during the survey period.

Spatial Changes in Circulation

Charts of the dynamic topography (0-200 dbars) of the survey areas of R/V *Protsion* in April-June 1972 and 1973 are shown in Fig. 1 and 2. The dates of the surveys in each sector of the area, between lines of demarcation AB and CD, are shown in the figures. Unfortunately, the sequence of investigations was different in the two surveys: work was conducted over the same period on the northeastern and southeastern slopes of the Newfoundland Grand Bank and on Flemish Cap Bank (ICNAF Divisions 3L, 3N, 3M) but on the southwestern slope of Grand Bank and in the Laurentian Channel (Div. 30, 3P and 4V) the survey was carried out in June 1972 and in April 1973.

Dynamic charts for the Grand Bank area for April-June 1970 were compiled earlier (Kudlo and Burmakin, 1972; Kudlo, 1973). Correlation between the dynamic charts themselves for the last 4 years (1970-73) shows that the general pattern of the circulation of waters in the ICNAF Area from South Labrador to Cabot Strait is very stable with time. Its seasonal and year-to-year fluctuations do not lead to a new interpretation of the pattern of horizontal circulation in particular periods, in the area investigated. Apparently, the main features of horizontal circulation develop under the influence of the bottom relief. The peculiarities and invariability (with time) of the bottom relief are the main factors, under the influence of which the Labrador Current, (flowing around the Grand Bank and meeting with the powerful flow of the Gulf Stream) carries its waters along quasi-stationary trajectories. Comparison of dynamic charts between themselves and with charts of the bottom relief of the area convinces us of this fact.

However, the foregoing does not mean that the circulation in the Grand Bank area and contiguous areas is invariable. Disturbances of a different origin can develop against the background of a quasi-stationary general circulation and these disturbances lead to a reconstruction of the current fields in some parts of the area without breaking the general system of circulation. Thus, anomalies in the general circulation can be formed at each specific moment in time.

Let us consider from this point of view the dynamic charts for the Grand Bank area for the second half of May 1971 (Kudlo, 1973) and 1972-73 (Fig. 1 and 2). The general scheme of circulation is, in principle, the same in these figures, but each current field has individual features. Thus in May 1972 on the southeastern slope of the Grand Bank (Div. 3N) a considerable proportion of the Labrador Current between 44° and 45°N turned to the east and followed in northeasterly direction along the outer edges of the Gulf Stream, mixing with its waters. In May 1971 an analogous branching of the Labrador Current waters was found to be considerably weaker. In May 1973 a disordered circulation, in the form of a number of vortexes, crests and hollows, was observed between the southeastern slope of the Grand Bank and Flemish Cap, (Fig. 2). Such a configuration of the current field apparently occurs as the result of dynamic interaction between the Labrador Current and Gulf Stream, the intensity of which changes differently with time. In the figures one can also see other features of the spatial circulation in the areas studied in the spring of 1972 and 1973.

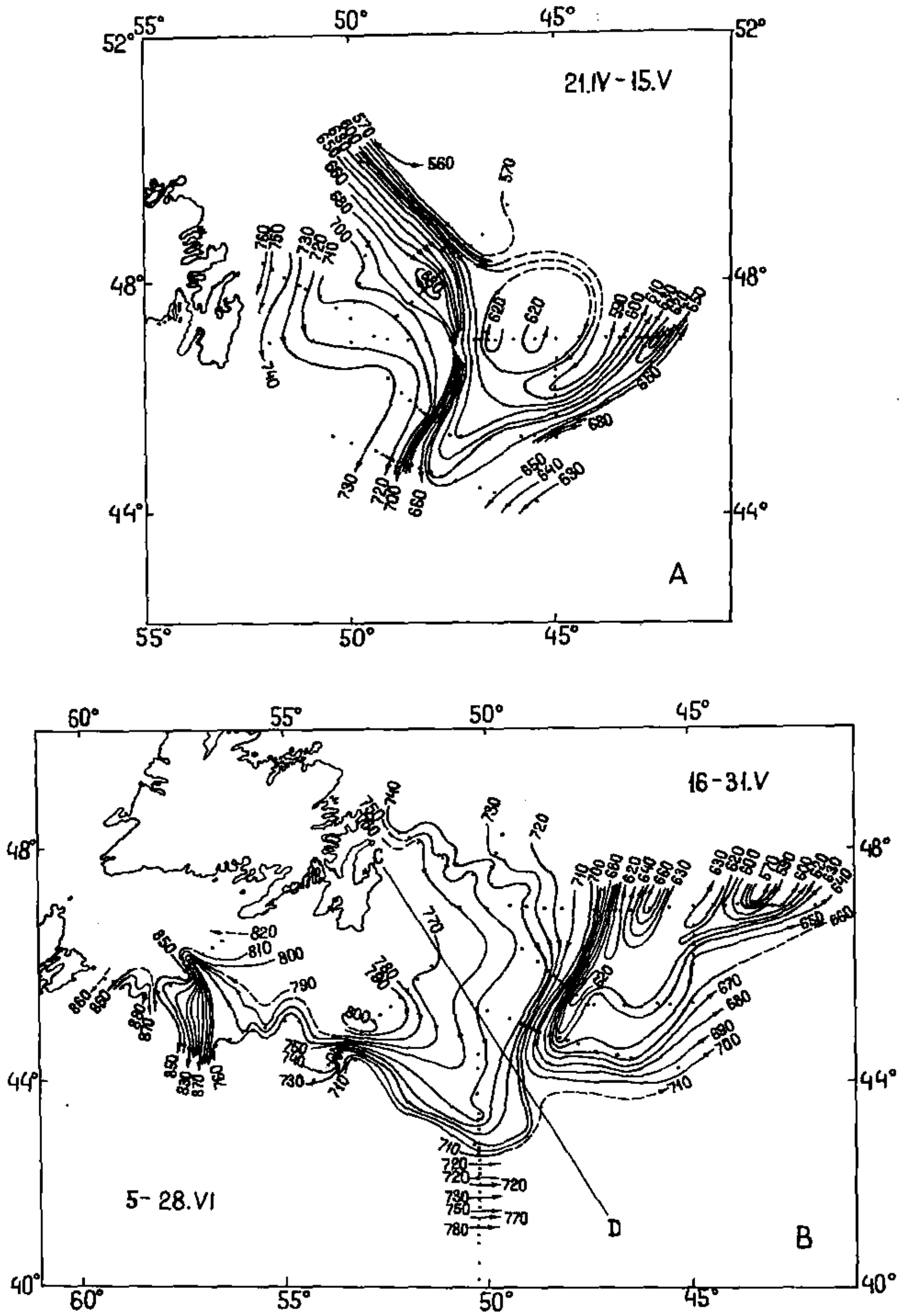

Fig. 1. Dynamic charts (0-200 dbars) from data of the 8th cruise of R/V *Protsion* in April-June 1972 (dates of survey in separate sectors of the area are shown in the figure).

CHANGES IN TRANSPORT OF THE LABRADOR CURRENT

For a quantitative assessment of the variability of the intensity of the Labrador Current, transports of the current on standard hydrological Sections 8-A, 6-A, 3-A and 4-A, for all observations conducted by PINRO research vessels in 1972-73, were estimated by calculating the dynamic velocities. For Section 4-A data are also given for 1971 in Table 1. (Standard USSR hydrological sections are shown in Fig. 1 of Burmakin's papers, this volume, p. 33).

Anomalies of transport for each period of observations were defined relative to long-term mean curves of water transport (Kudlo, 1973). It should be noted that the curve of seasonal changes in transport of the Labrador Current in the ABC sector of Section 8-A, in the 0-2,000 m layer, (calculated from long-term mean data) was very similar to the curve of seasonal changes in this current in the 0-1,000 m layer, which is given in the paper by Burmakin, mentioned above. The only difference being that year-to-year changes in transport in each month are one and a half times larger in the 0-2,000 m layer (0-bottom) than in the 0-1,000 m layer ($\pm 3 \times 10^6$ m^3/sec against $\pm 2 \times 10^6$ m^3/sec.).

In Div. 2J, transport of water across Section 8-A was about normal at the end of 1972, whereas it had considerably increased by June 1973 and exceeded the normal by 2.8×10^6 m^3/sec. in the 0-2,000 m layer, and by 1.9×10^6 m^3/sec. in the 0-1,000 m layer (Table 1).

In Div. 3L, on Section 6-A, which crosses the channel between the northeastern slope of the Grand Bank and Flemish Cap, the transport of the Labrador Current was higher than normal in the spring of 1972 (Table 1). In April 1973 the transport was somewhat higher

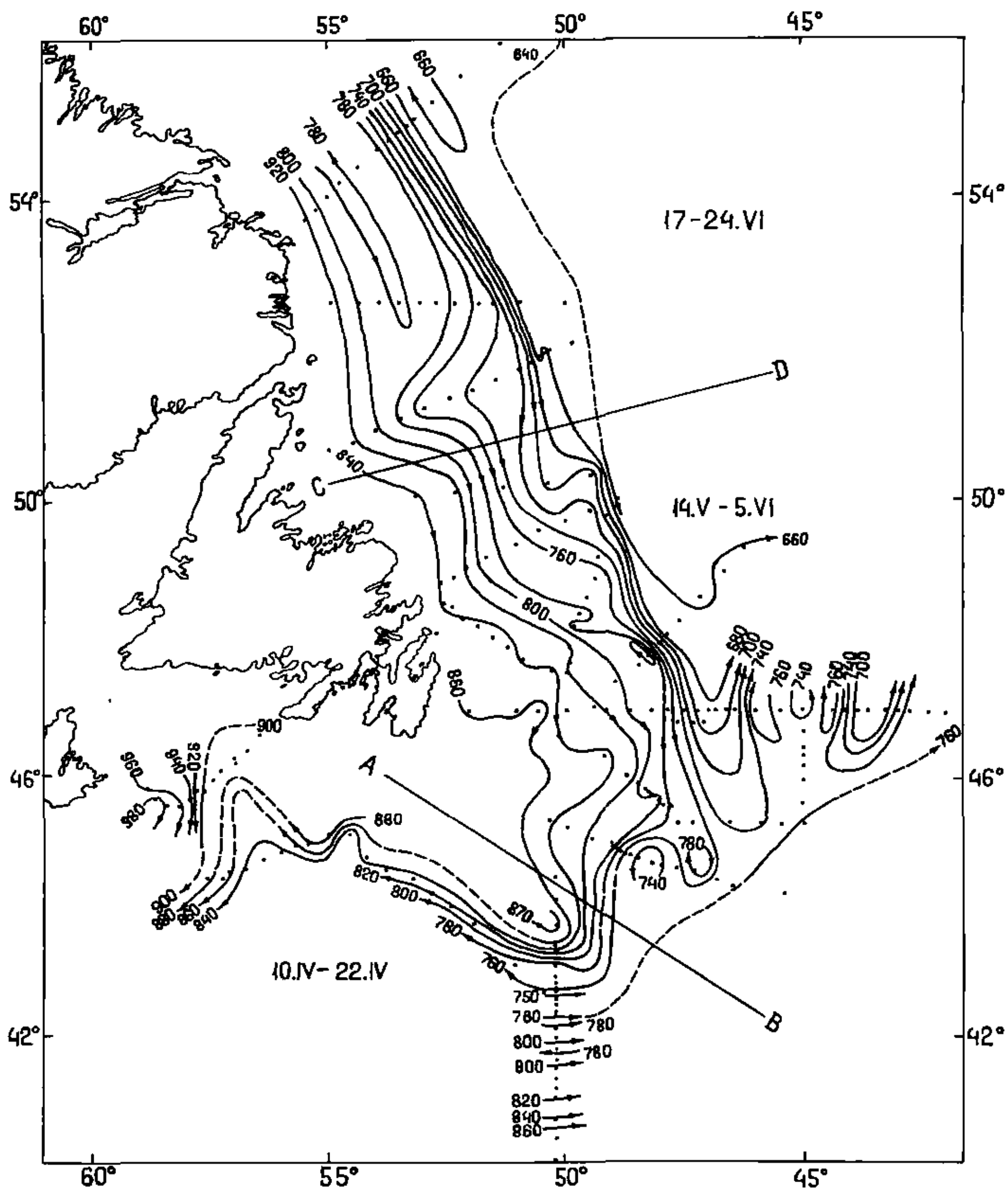

Fig. 2. Dynamic charts (0-200 dbars) from data of the 11th cruise of R/V *Protsion* in April-June 1972 (dates of survey in separate sectors of the area are shown in the figure).

TABLE 1. Transport of the Labrador Current and its anomalies on some standard sections in 1971-73 ($10^6 m^3$/sec.).

Sections and layers	Date	Transport		
		Observed	Norm	Anomaly
8-A; A B C 0-2,000 m	27-28 Oct 1972	4.89	4.9	0.0
	22-24 June 1973	7.09	4.3	+2.8
8-A; A B C 0-1,000 m	27-28 Oct 1972	4.70	4.9	-0.2
	22-24 June 1973	6.13	4.2	+1.9
6-A; H^1GH^2 0-bottom	10 April 1972	3.03	3.0	0.0
	1-2 May 1972	6.33	3.1	+3.2
	25-26 May 1972	5.90	3.2	+2.7
	26-27 April 1973	3.75	3.1	+0.6
	24-25 May 1973	2.29	3.2	-0.9
	12-13 July 1973	2.32	3.4	-1.1
3-A 0-2,000 m	18-19 April 1972	3.99	5.0	-1.0
	22-23 April 1972	4.14	4.9	-0.8
	16-17 May 1972	8.64	4.2	+4.4
	15-16 May 1973	6.66	4.2	+2.5
	11-12 July 1973	0.44	2.6	-2.2
4-A 0-2,000 m	24-25 April 1971	2.62		
	18-19 May 1971	1.43		
	27 June-2 July 1971	1.75		
	19-20 Dec 1971	1.36		
	24-25 April 1972	6.10		
	20-21 May 1972	8.75		
	18-20 May 1973	9.07		

than normal (by +0.6 x 10^6 m^3/sec.), but by May and in July it had decreased giving negative anomalies of about 1 x 10^6 m^3/sec. Thus, despite an increased influx of Labrador Current water to the northeastern slope of Grand Bank (see data for Section 8-A), peculiarities of the horizontal circulation hindered the inflow of this water south of 47°N (see Fig. 2), and it is this factor that caused the negative anomalies of the Labrador Current in that area.

In Div. 3N, in May 1973, the transport of the Labrador Current was higher than normal by 2.5 x 10^6 m^3/sec. on the southeastern slope of the Grand Bank (Section 3-A), but by mid-July the intensity of the Labrador Current had considerably decreased in that area. It should be noted that in the Spring of 1973 annual changes in transport on Sections 6-A and 3-A were opposite in character to those in 1972; in 1973 the tendency was towards closer agreement with the long-term mean for this period.

The water transport on Section 4-A, which is slightly to the north of Section 3-A, was calculated from Stations 1 to 12 (46°20'N, 49°05'W - 45°20'N, 47°22'W). In the shallow area the transport was calculated to the bottom, and offshore it was calculated to the maximum depth of observations (2,000 m). This made it possible to take into account the total volume of water masses moving in southwesterly direction, both over the shallows and over the depths. Anomalies were not calculated for this section in the absence of a normal curve of transport. However, values of water transport across this section (Table 1) show that the total transport of water, within the boundaries mentioned, was in a southwesterly direction, and was extremely variable, and in April-May 1972-73 the volume transport across this section was between 2-4 times greater than in the same period of 1971.

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Salinity of Waters in the Newfoundland and South Labrador Areas in April-June 1972 and 1973

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INTRODUCTION

This paper deals with salinity data collected on standard hydrological sections in the ICNAF area (see Fig. 1, Burmakin's paper, this volume, p. 33) during the 8th and 11th cruises of R/V *Protsion* and during the 8th and 11th cruises of R/V *Perseus III* in 1972 and 1973; the cruises were conducted mainly in Spring.

RESULTS

The maps of horizontal distribution of salinity on the surface and near the bottom in the observation areas, in April-June 1972 and 1973, are compiled from data obtained by R/V *Protsion* (Fig. 1-3). Dates of surveys in some parts of the area are given in the figures. These maps show some peculiarities of the salinity distribution and together with the dynamic charts they give detailed information concerning the environmental conditions during the period of the hydrological surveys.

Comparison between the maps of salinity and dynamic topography of these surveys confirms our conclusion (Kudlo, 1973) that the salinity field is determined by the current field and, through it, by the bottom relief.

Average values of salinity in the 0-200 m layer on standard hydrological sections crossing the Labrador Current (Table 1) were calculated as quantitative indices. Norms and anomalies of salinity at the date of observation were determined with the help of mean curves of the annual values of salinity, as obtained by us previously (Kudlo and Burmakin 1971, 1972; Kudlo, 1973).

TABLE 1. Salinity of the Labrador Current and its anomalies in the 0-200 m layer on standard sections in 1972-73 in °/₀₀.

Sections	Date	Salinity Observed	Salinity Normal	Salinity Anomaly
8-A (B)	27-28 Oct 1972	33.15	33.55	-0.40
	22-24 June 1973	33.41	33.88	-0.47
	10 April 1972	33.46	33.91	-0.45
	1-2 May 1972	33.76	33.80	-0.04
6-A (G)	25-26 May 1972	33.64	33.77	-0.13
	26-27 April 1973	33.74	33.82	-0.08
	24-25 May 1973	34.04	33.76	+0.28
	12-13 July 1973	33.59	34.00	-0.41
	24-25 April 1972	33.85	34.09	-0.24
4-A	20-21 May 1972	33.82	34.02	-0.20
	18-20 May 1973	33.30	34.03	-0.73
	18-19 April 1972	33.44	33.87	-0.41
	22-23 April 1972	33.34	33.84	-0.50
3-A	16-17 May 1972	33.37	33.70	-0.23
	15-16 May 1973	33.72	33.70	+0.02
	11-12 July 1973	33.61	34.01	-0.40

The data in Table 1 show that in the spring of 1973, negative anomalies of salinity predominated throughout the Labrador Current. This is evidently connected with the increased inflow of water from the Labrador Coast. However, we have not, as yet, managed to find a definite relationship between the anomalies of salinity and water discharge.

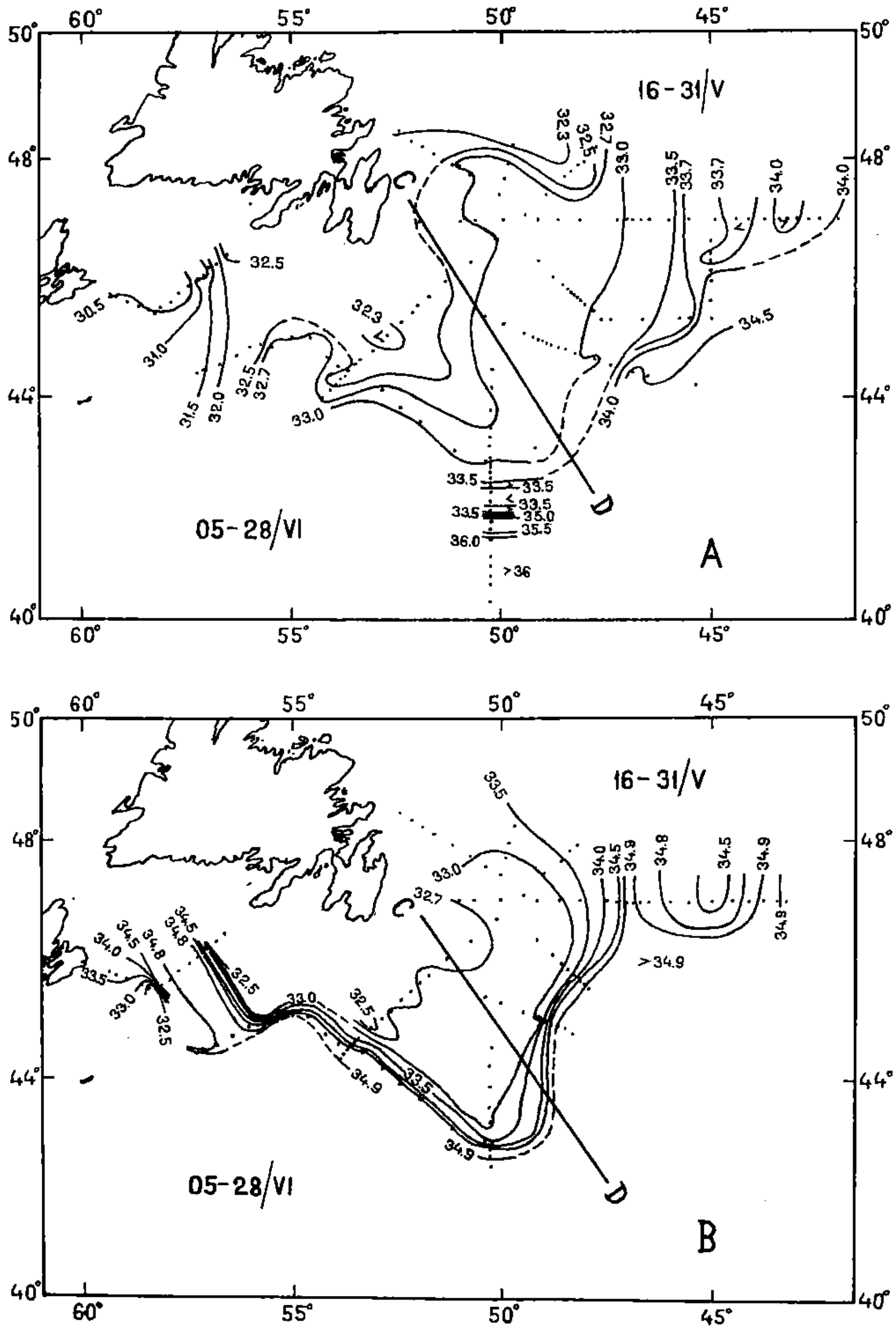

Fig. 1. Distribution of salinity in the Newfoundland area on the surface (A) and near the bottom up to a depth of 2,000 m (B) from data of the 8th cruise of R/V *Protsion* in May-June 1972.

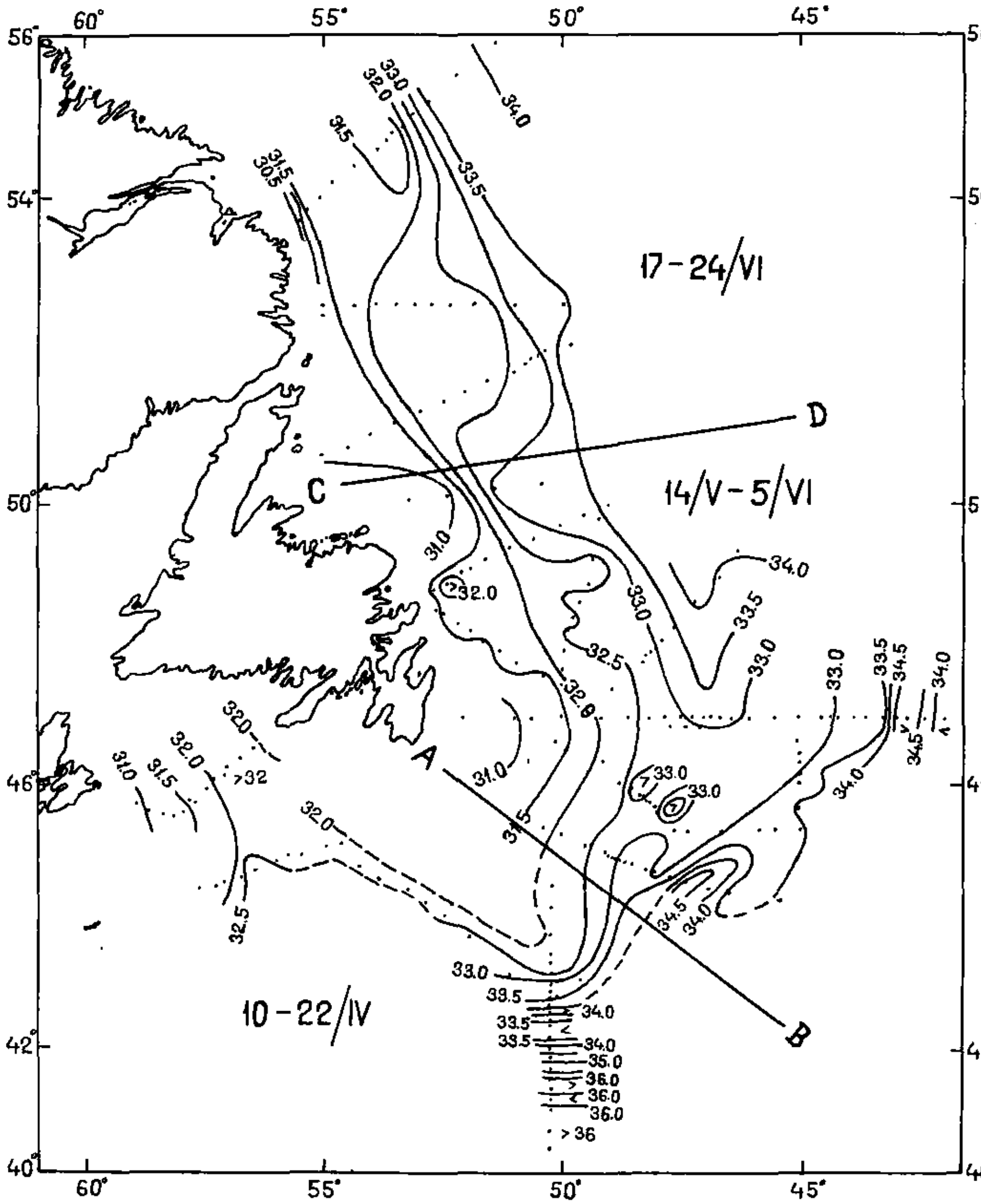

Fig. 2. Distribution of salinity on the surface in the South Labrador and Newfoundland areas from data of the 11th cruise of R/V *Protsion* in April-June 1973.

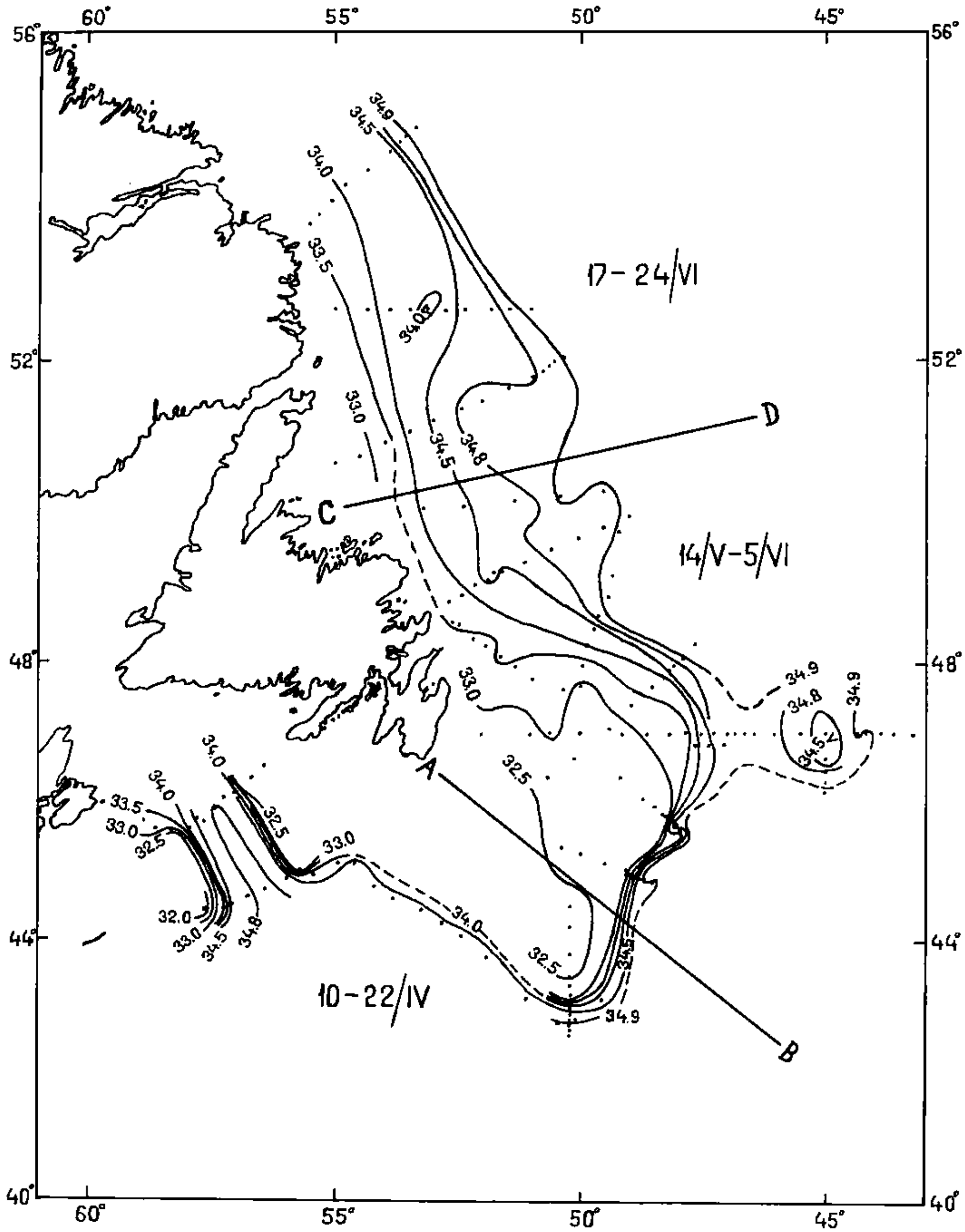

Fig. 3. Distribution of salinity near the bottom (up to a depth of 2,000 m) in the South Labrador and Newfoundland areas from data of the 11th cruise of R/V *Protsion* in April-June 1973.

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International Ice Patrol Operations 1972 – Why So Many Icebergs?

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Introduction

Each spring, ice drifts southward along the coast of Labrador and Newfoundland toward the area of the North Atlantic Ocean near the Grand Banks, a region which is traversed by much shipping. Although sea ice is a hazard to this shipping, large pieces of glacial ice in the form of icebergs create the real menace. From March through June when this iceberg threat to the mariner is greatest, the prevalence of fog and the presence of fishing vessels compound this navigation problem and could lead directly to a major marine disaster.

The most well-known disaster of this type was the sinking of the luxury liner *Titanic* on 15 April, 1912 less than 3 hrs after striking an iceberg in the frigid water south of Newfoundland. The sinking of this supposedly "unsinkable ship" on her maiden voyage caused a public outcry demanding a service to the mariner which would advise him of potentially dangerous icebergs. In direct response to this plea, the following year, the International Convention for the Safety of Life at Sea (SOLAS) established an Ice Patrol on the Grand Banks of Newfoundland. While this multi-nation treaty provided for financial support from all members, the United States Coast Guard was charged with actually conducting the International Ice Patrol. With the exception of the war years, the Coast Guard has conducted this patrol each year since 1913. In 1972 the operational costs were being shared with the United States by 18 other maritime nations. Today this work continues under provisions of the 1960 SOLAS treaty and the United States Code.

International Ice Patrol must be considered a success, since no lives have been lost due to icebergs in the area under Ice Patrol's cognizance since its inception. At this point one might well say that with all the advances in navigational equipment, the need for Ice Patrol is diminishing. However, this is not the case. As recently as 1959, the *Hans Hedtoft*, a modern well-equipped ship on her maiden voyage, presumably collided with an iceberg off the west coast of Greenland and sank. All 95 persons on board were lost. Clearly then the need for International Ice Patrol still exists.

The iceberg threat varies, often drastically, from year to year (Fig. 1). In some years, such as 1966, no icebergs drifted south of 48°N. On the other extreme, over 1,000 icebergs have drifted south of the 48th parallel during several years. For example in 1929, 1,350 such icebergs were reported.

1972 Operations

However, no year in the 60 year history of International Ice Patrol compares with 1972 for severity. That year 1587 icebergs were reported to have drifted below 48°N to menace shipping. As a result, the 1972 Ice Patrol season was the longest in history–beginning on 29 February and extending until 4 September. By April, icebergs had drifted south of 42°N. This made it necessary for Commander, International Ice Patrol to assign a Coast Guard cutter to standby the southernmost iceberg and broadcast warnings to shipping transiting the area. For the first time in 13 years, ice conditions were severe enough on the Grand Banks to warrant deployment of a Coast Guard vessel specifically for this purpose, and this service had to be continued into July. By May, there were more than 700 icebergs scattered over the area of direct concern to the International Ice Patrol.

To stay abreast of changing ice conditions and keep the mariner well advised, Commander International Ice Patrol utilizes all pertinent information that is available. Some of this information is provided by Coast Guard units assigned to Commander,

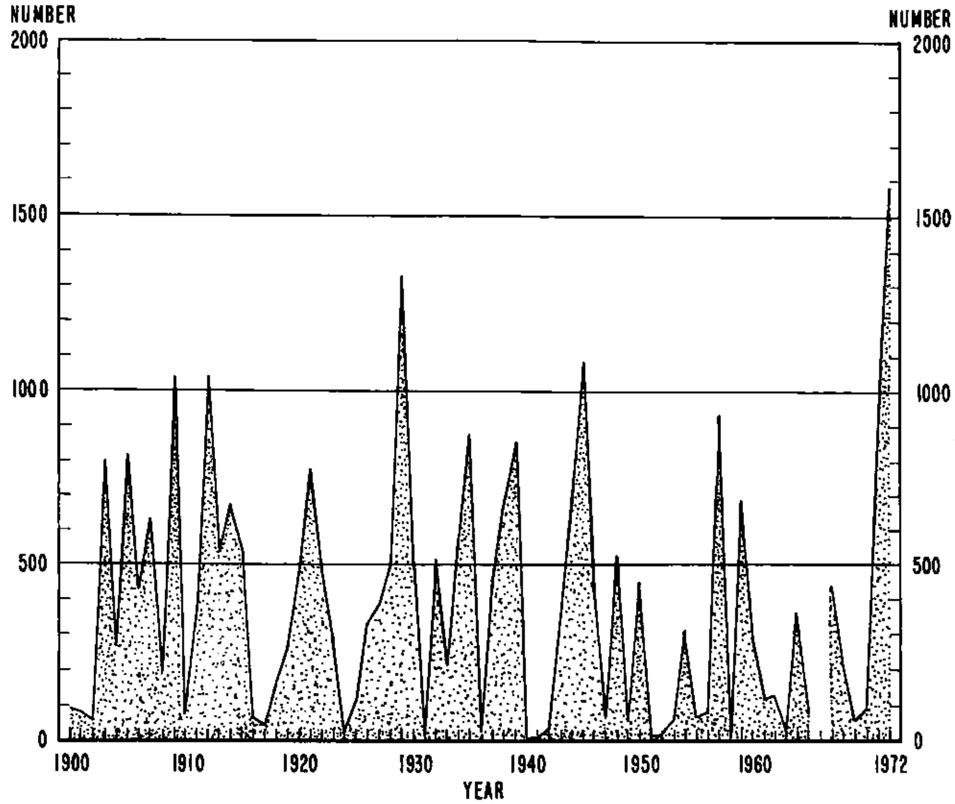

Fig. 1. The annual iceberg sightings south of 48°N (1900-1972).

International Ice Patrol for the duration of the ice season. One such unit was a modern C-130 turboprop aircraft which was stationed at Canadian Forces Base, Summerside, Prince Edward Island during the 1972 ice season. The task of the aircraft personnel was to survey the Ice Patrol area as frequently as operationally feasible in search of icebergs. Even with this modern aircraft it took 3 days to fly over the area of primary interest to Ice Patrol. As visual sightings were often hampered by fog and clouds during this time of year, a side-looking airborne radar (SLAR) was tested during the 1972 season. Though, such experiments have been conducted during various ice seasons since 1957, none of the systems to date has been totally satisfactory. The major problem was trying to distinguish icebergs from slow moving ships. As an all weather detection device would be invaluable, it is felt that research on this project will continue until a suitable device is developed.

Besides a vessel to monitor the southernmost iceberg, Commander, International Ice Patrol has another Coast Guard cutter at his disposal. This vessel is equipped to conduct oceanographic studies on the Grand Banks during the ice season (Fig. 2). As in most years since 1948, the Coast Guard Cutter *Evergreen*, a 180-ft converted buoy tender, was given this task in 1972. With a crew supplemented by scientists and technicians from the Coast Guard Oceanographic Unit, three cruises of a month's duration each were conducted. The primary mission was to obtain current information to the south and east of the Grand Banks. The information provided by Coast Guard and other sources was synthesized by Commander, International Ice Patrol, who in turn supplied the mariner with twice daily ice bulletins.

Discussion of Data

It now seems appropriate to look back on data obtained during the 1972 ice season and attempt to determine why it was such a severe year. To do this one must consider the important factors which affect the iceberg threat. These according to Soule *et al* (1950) are:

Iceberg mortality during the drift south,
Efficiency of iceberg transport to the northwest Atlantic Ocean,
Supply of icebergs available.

Iceberg mortality during the drift south is affected by three primary items:

Water temperature,
Air temperature,
Ocean waves/sea ice.

Of course the warmer the temperature of the water in which an iceberg is floating the more rapidly the iceberg will melt. During the 1972 ice season, sea surface temperatures along the eastern coast of Canada were colder than normal. This anomalous condition first became apparent during February (Fig. 3), and was most pronounced in May (Fig. 4), when temperature anomalies of more than 2°C below normal were recorded. It was not until August that sea temperatures returned to normal.

This unseasonably cold condition resulted in the 0°C sea surface isotherm remaining south of Newfoundland through March (Fig. 5). Even as late as the end of June, this isotherm extended as far as the northern Newfoundland coast (Fig. 6).

Cold water was also found to some depth, as shown in vertical temperature profiles which were constructed from data obtained during the aforementioned oceanographic cruises. Four examples of these profiles which cross the Labrador Current will be presented. The first profile (Fig. 7) is along Section A2 which is located between the continental shelf and Flemish Cap. Here water temperatures reached a minimum of less than -1.6°C and the

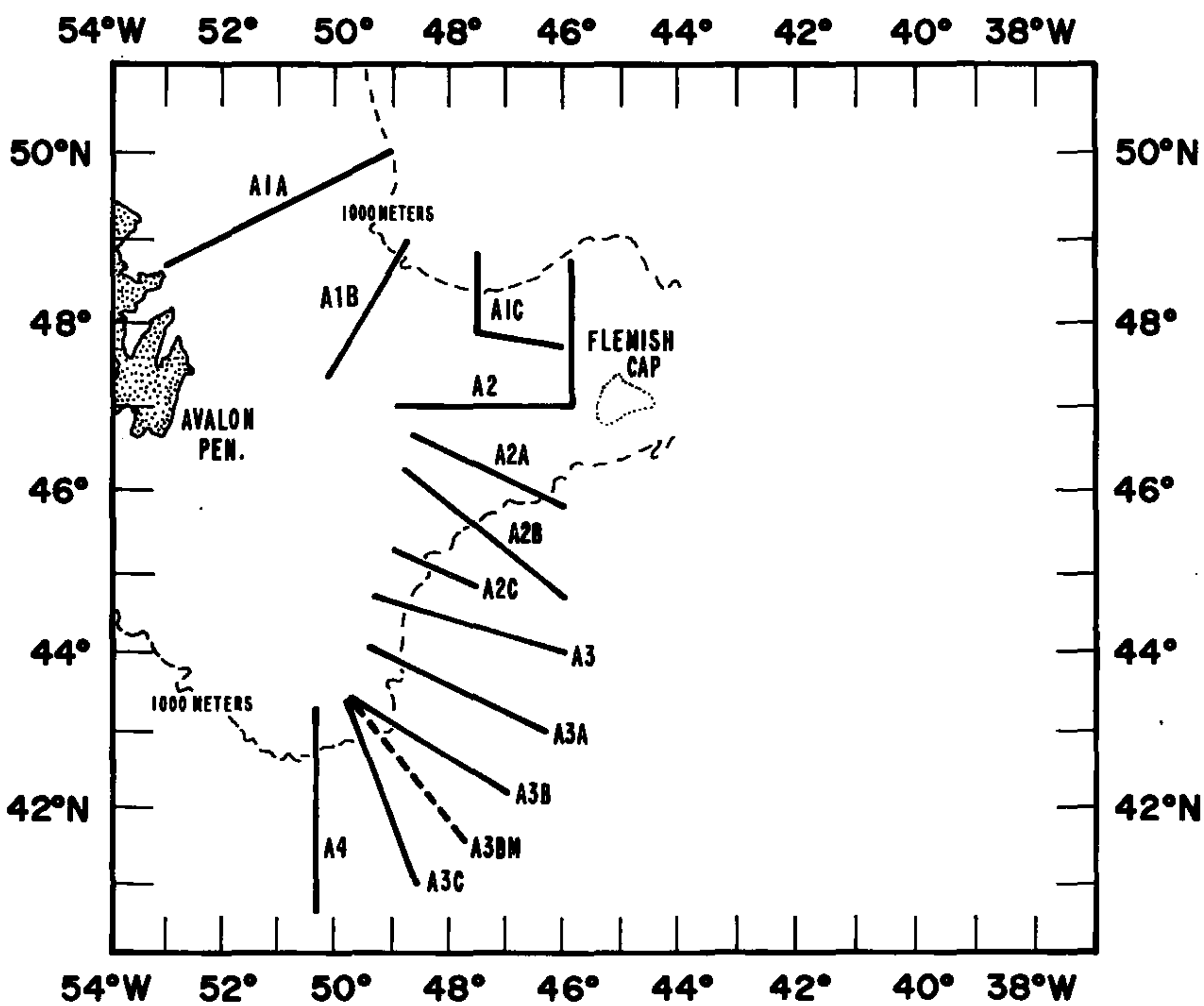

Fig. 2. Standard International Ice Patrol Sections in the Grand Banks area.

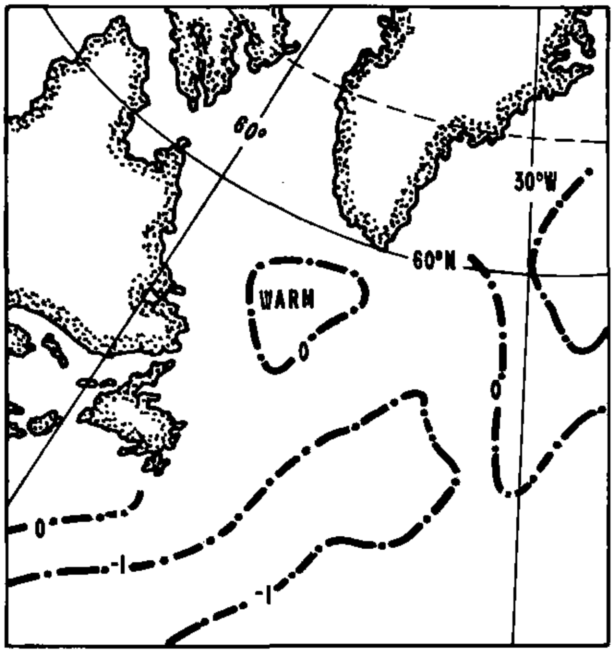

Fig. 3. Mean sea surface temperature anomalies (°C) for February 1972 (after Sanderson 1972*a*)

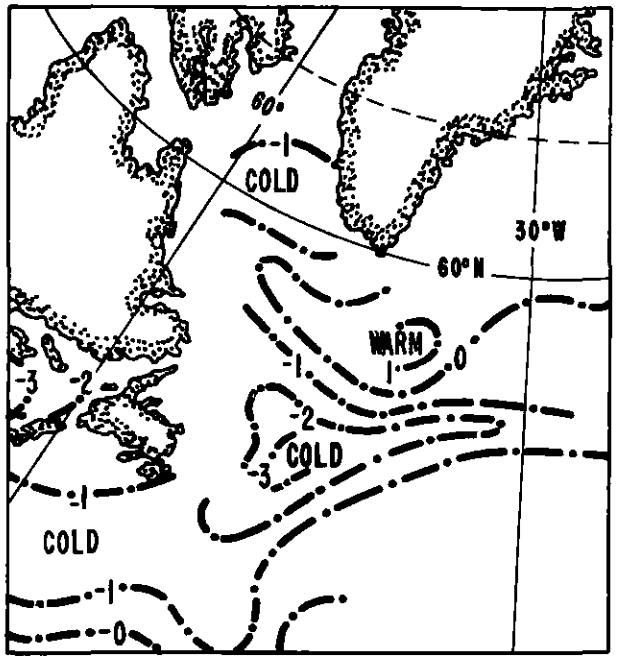

Fig. 4. Mean sea surface temperature anomalies (°C) for May 1972 (after Sanderson 1972*b*)

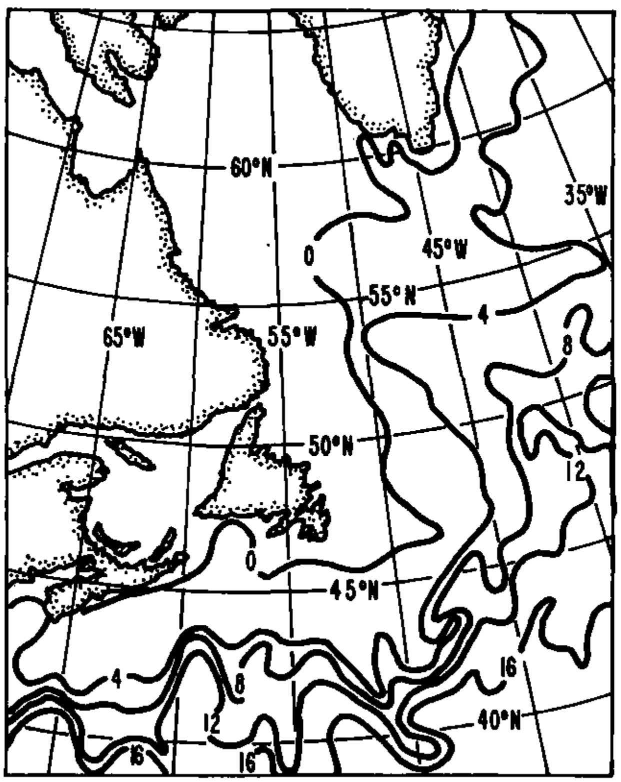

Fig. 5. Sea surface isotherms (°C) for March 1972 (after Royal Met. Off).

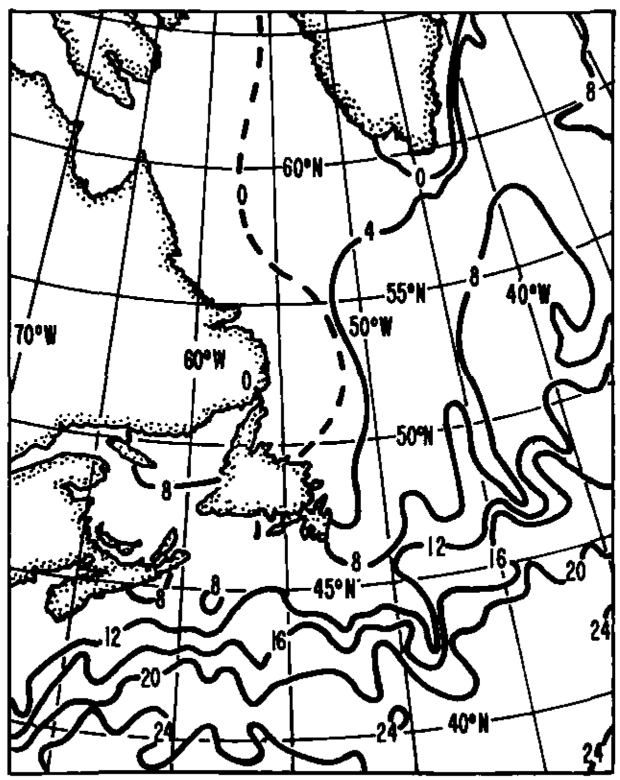

Fig. 6. Sea surface isotherms (°C) for June 1972 (after Sanderson 1972*b*).

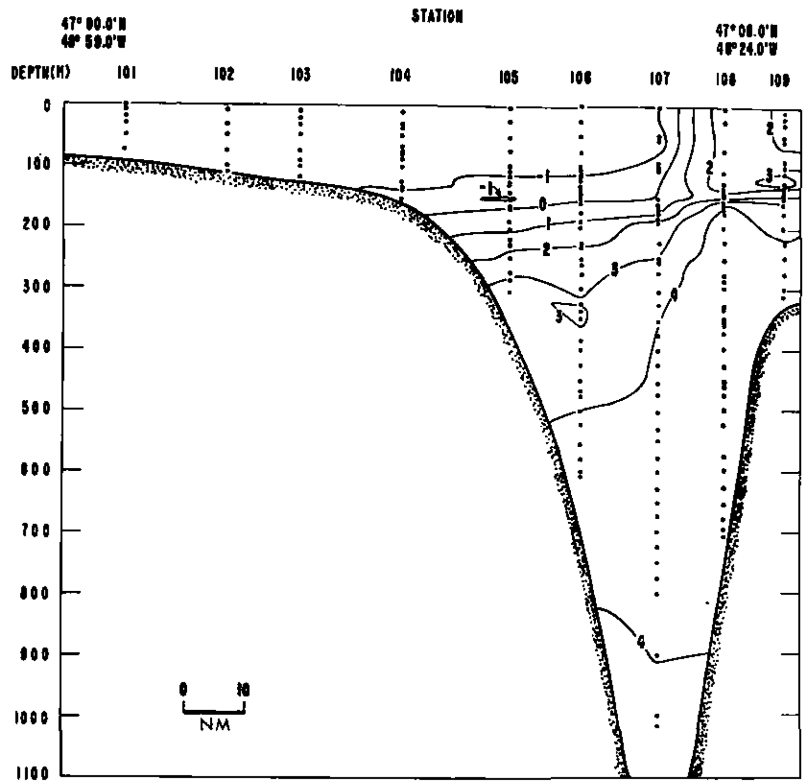

Fig. 7. Vertical cross section of temperature (°C) on Standard Section A2 on 7-8 April 1972 prepared from data of USCGC *Evergreen*.

0°C isotherm extended to a depth of more than 150 m for nearly the entire section. This isotherm is significant as icebergs are calved from fresh water glaciers and little melting will occur below the water line until the water temperature exceeds 0°C. This cold water extended at least as far south as the Tail of the Bank as noted on the 18-19 April occupation of Section A4 (Fig. 8). Although not as extensive as the cold core found on Section A2, the water column is still influenced by the Labrador Current. Here temperatures lower than -1.2°C were recorded and the 0°C isotherm still extended below 150 m.

In mid-May, the Labrador Current, was very evident on Section A3 (Fig. 9). Temperatures below -1°C were present and the 0°C isotherm penetrated to more than 150 m. The mid-June occupation of this same section (Fig. 10) indicates that the temperature of the surface water had greatly increased. However, a cold core of water with negative temperatures persisted near the continental shelf. Considering the fact that the cold core of the Labrador Current extended well south and persisted well into the season, it is felt that the water temperatures in 1972 were very favorable for a heavy ice season.

The second important item affecting iceberg mortality is the air temperature. During the winter of 1971-72 frost degree days were recorded at eleven stations located along the Labrador coast and along the coasts of Greenland (U.S. Navy SP-60 [72]). Record frost degree day accumulations were observed at seven of these stations. Accumulations at the other four stations were normal or above. Also, for the entire first half of 1972 air temperatures along the eastern Canadian coast were below normal and temperature anomalies were greatest during the early part of this period. In February, for instance, the average temperature was more than 4°C below normal (Fig. 11). Toward summer, temperatures approached normal; however, as late as May (Fig. 12), the temperature was still more than 2°C below normal.

Temperatures recorded at four stations along the eastern Canadian coast are typical of the low values observed during the spring of 1972 (Table 1). It was not until June that temperatures rose sufficiently high enough to cause any appreciable melting. Even then, all the stations except St. John's reported temperatures below normal. Thus, as in the case of sea temperature, the lower than average air temperatures were so low as to

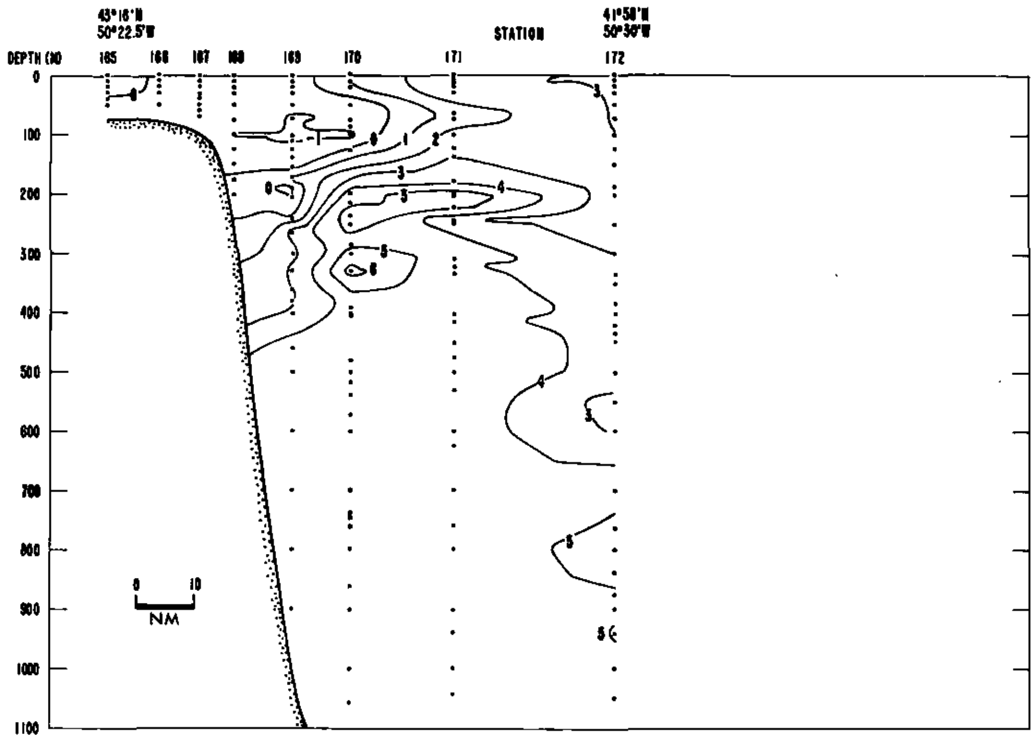

Fig. 8. Vertical cross section of temperature (°C) on Standard Section A4 on 18-19 April 1972, prepared from data of USCGC *Evergreen*.

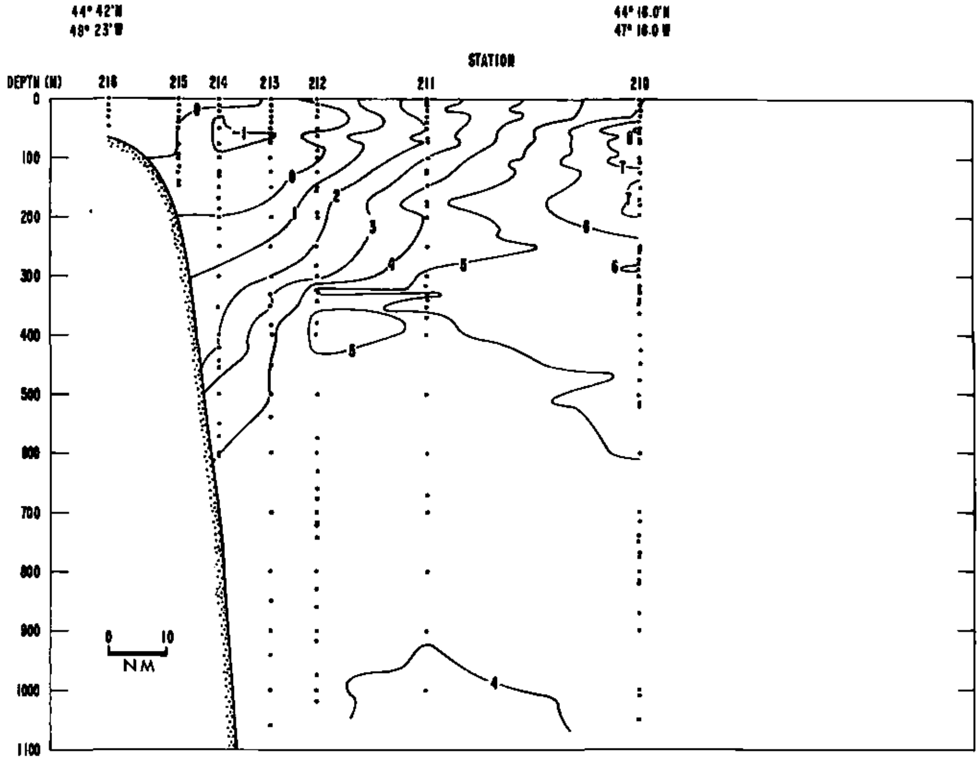

Fig. 9. Vertical cross section of temperature (°C) on Standard Section A3 on 13-14 May 1972, prepared from data of USCGC *Evergreen*.

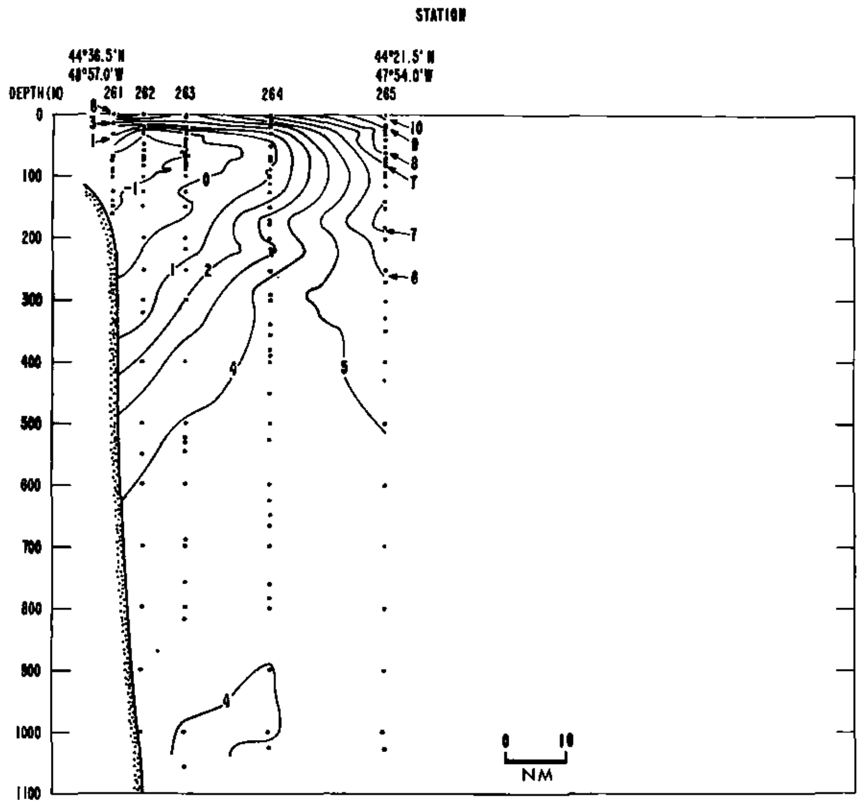

Fig. 10. Vertical cross section of temperature (°C) on Standard Section A3 on 16-17 June 1973.

cause minimal iceberg melting until late in the ice season. This, therefore, aided in reducing iceberg mortality.

The final item which affects iceberg mortality is wave action/sea ice. Icebergs exposed to rough seas are subjected to destructive forces caused by surface wave motion. One factor that effectively reduces the effects of wave action is sea ice, which will greatly dampen waves traveling only a short distance under it. During the 1972 ice season, excessive amounts of sea ice were present. From January through June the sea ice extended further south and east than normal. Compared to the normal, January (Fig. 13) was an extremely heavy month for sea ice, and as late in the season as May (Fig. 14), sea ice still lingered off the coast of Newfoundland. Usually by that date the ice should have retreated well up the Labrador coast. Thus in 1972, sea ice conditions were such as to protect icebergs to much greater an extent than during an average ice year. Winds, which also affect iceberg mortality, will be discussed later under a separate heading.

It has now been shown that in 1972 all factors that affect iceberg mortality which have been discussed—air temperature, sea temperature, and sea ice — favored reduced

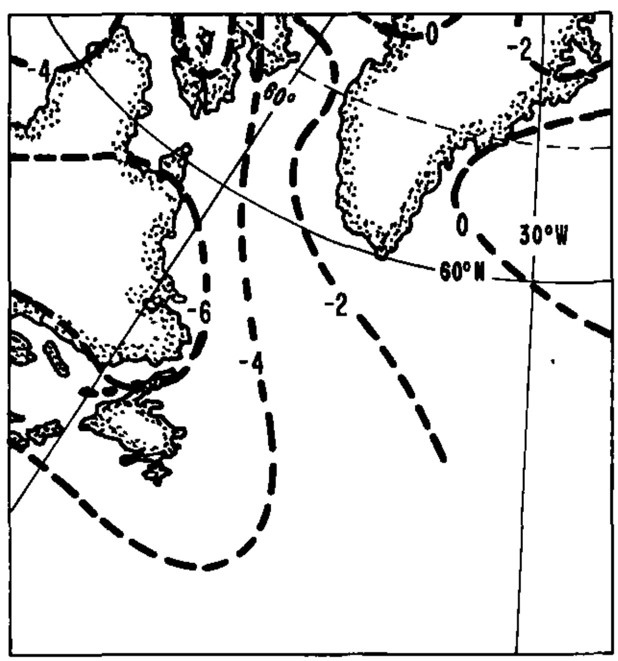

Fig. 11. Mean air temperature anomalies for February 1972) after Sanderson, 1972*a*).

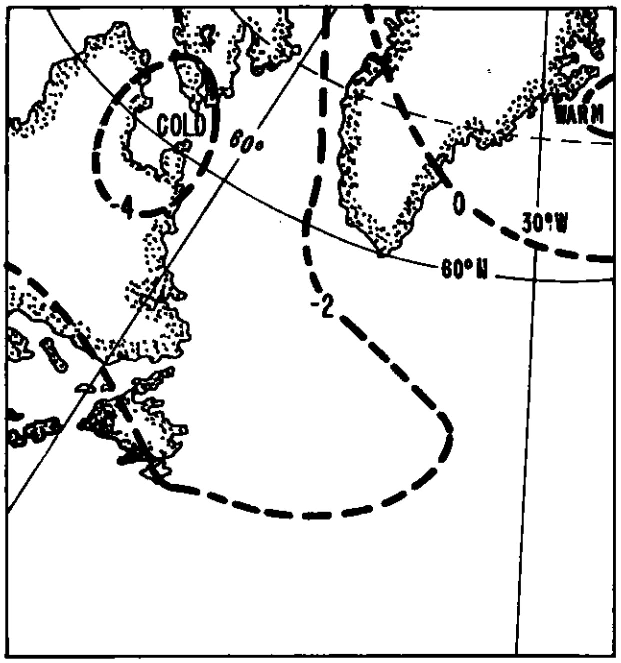

Fig. 12. Mean air temperature anomalies (°C) for May 1972 (after Sanderson, 1972*b*)

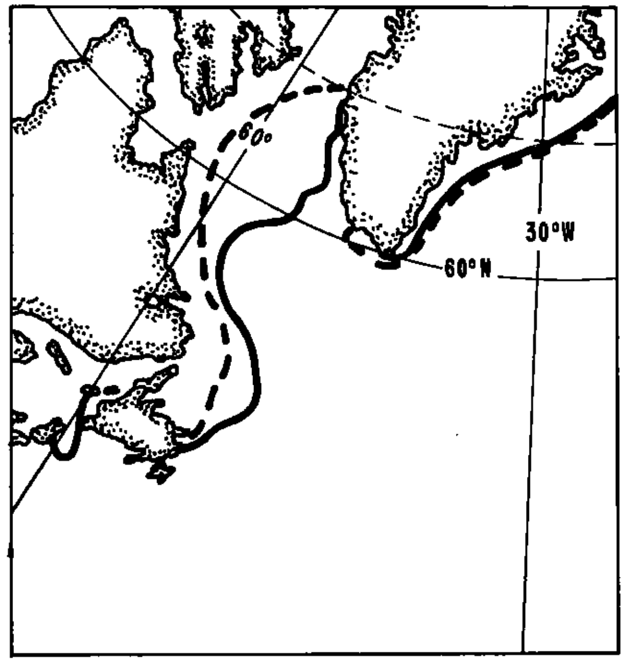

Fig. 13. Normal January and actual January 1972 extremes of open pack ice (after Sanderson, 1972*a*).

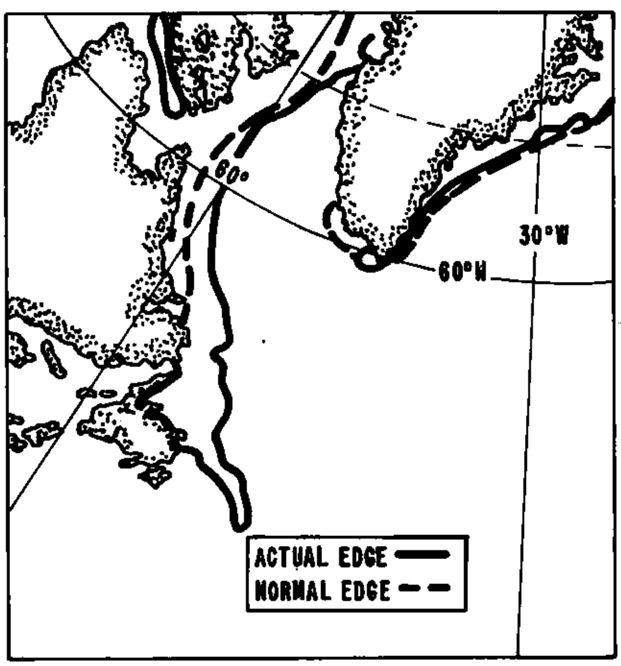

Fig. 14. Normal May and actual May 1972 extremes of open pack ice (after Sanderson, 1972*b*).

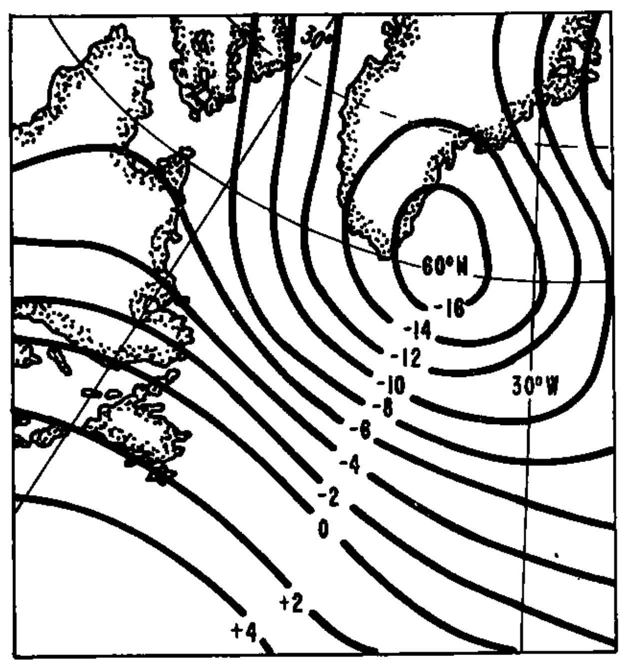

Fig. 15. Mean surface pressure anomalies (MB) for January 1972 (after Sanderson, 1972*a*).

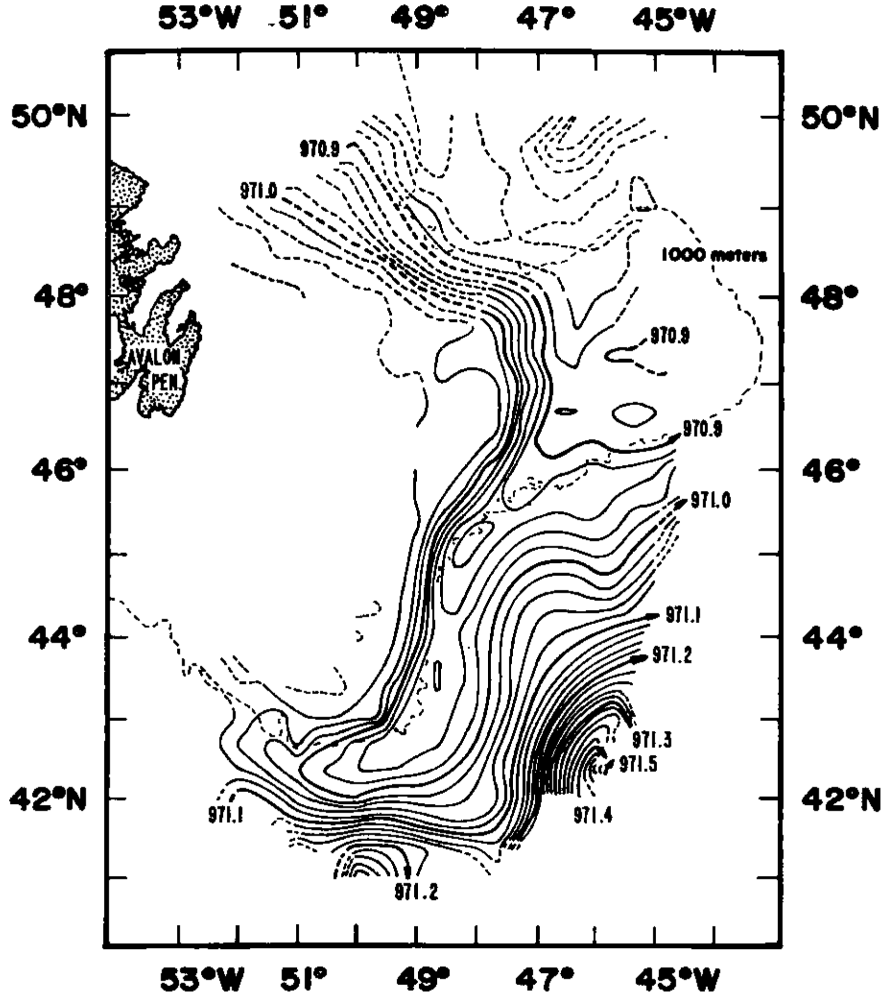

Fig. 16. April normal dynamic topography of the sea surface relative to the 1000 dbar surface (after Schultz).

iceberg mortality during the journey south.

The second major factor affecting the iceberg threat is the efficiency of iceberg transportation to the northwest Atlantic Ocean. This factor can be divided into two distinct parts:

Influence of the wind,
Influence of ocean currents.

Once berg reach the Labrador Current, all winds, except those out of the north and northwest, hinder the drift of bergs south. A westerly wind causes the bergs to drift from the Labrador Current into the ice-free Labrador Sea where their destruction is hastened by wave action and the warmer sea water temperatures there. Winds from the east cause the icebergs to drift out of the Labrador Current towards the coast line where they may become trapped or grounded. Of course, a southerly wind tends to slow the southward progress of the icebergs. Also, these winds are warm, aiding deterioration.

For the majority of the first half of each year, the winds around the Labrador Sea are generally controlled by the Icelandic Low. Thus during this time of year, the winds along the Labrador coast are frequently from the north - northwest. This flow was exaggerated during the 1972 ice season by an anomalously deep low pressure system. As in the January case (Fig. 15), each month had an anomalous wind which tended to emphasize southerly iceberg drift in the Labrador Current. This also acted to increase the speed of advance of the icebergs toward the Grand Banks. Thus the winds in 1972 increased the iceberg threat of shipping.

The second factor affecting the efficiency of transporting icebergs to the northwest Atlantic Ocean is the ocean currents. This effect is extremely important since about 90% of an iceberg's mass is below the surface of the water. Of immediate concern is the Labrador Current, which flows along the Labrador coast carrying icebergs southward. It has already been noted that the cold core of this current extended to the Tail of the Bank during the 1972 ice season.

Although no current data along the coast of Labrador are available for early 1972, much interesting information was collected below the 48th parallel. The first indication of the velocity of the Labrador Current in 1972 was obtained from a survey conducted by the U.S. Coast Guard Cutter *Sherman* in late March along Section A2 (Fig. 2). During this survey geostrophic velocities of up to 40.1 cm/sec were noted. Commencing in April, the U.S. Coast Guard Cutter *Evergreen* conducted three extensive dynamic surveys to the east of the Grand Banks. These surveys consisted of station taking along a number of these standard sections in an area from just above Flemish Cap to the Tail of the Bank and from the continental shelf east to the North Atlantic Current (Fig. 2).

The Coast Guard has conducted similar studies for nearly 40 years. In 1964, Soule (1964) utilized 22 years of this data to produce average dynamic topography charts for the months of April, May, June and July. This year these charts were updated by International Ice Patrol Division, Coast Guard Oceanographic Unit (Schultz, 1974) to include 32 years of data. In the "normal chart" for April (Fig. 16), the three prominent dynamic features of this area can be noted. To the left is the southerly flowing Labrador Current. The meanders of the North Atlantic Current are seen on the right. Between these two currents is an area of generally lower dynamic height which consists of water from

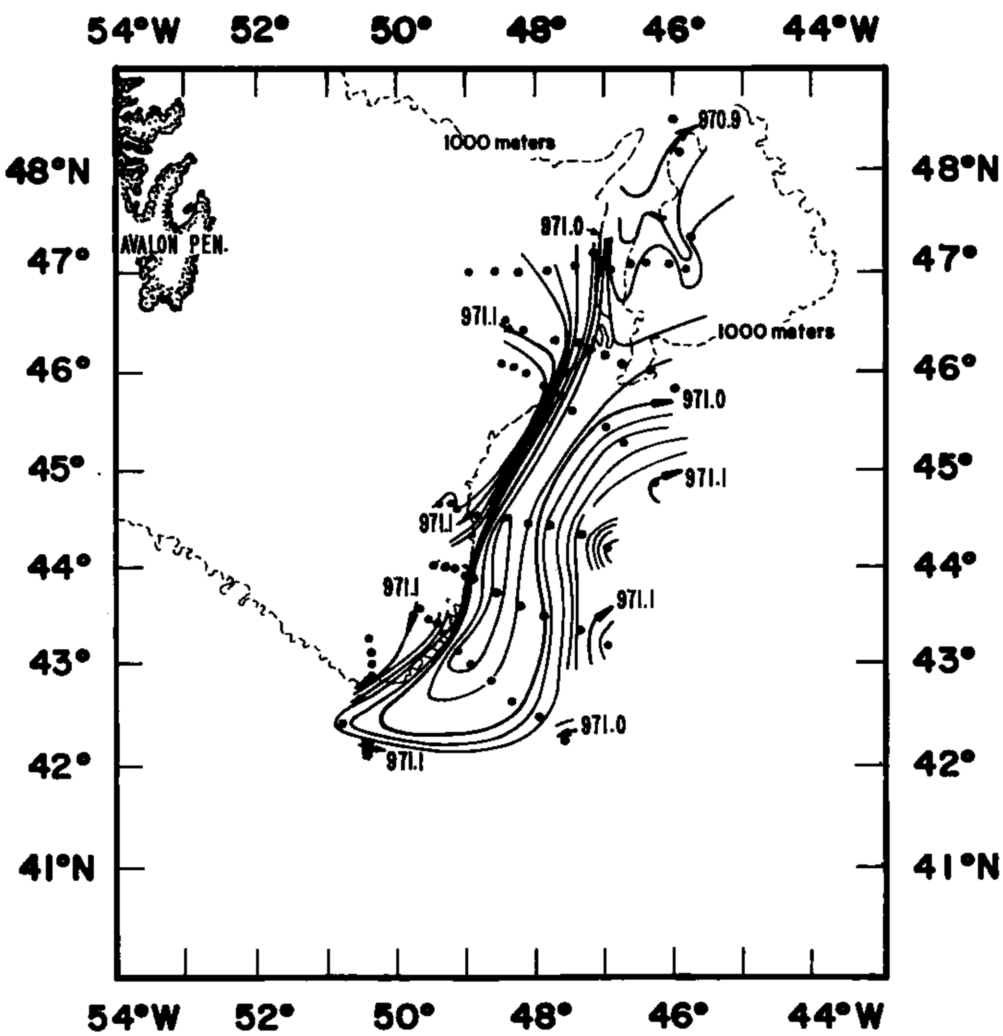

Fig. 17. April 1972 normal dynamic topography of the sea surface relative to the 1,000 dbar surface.

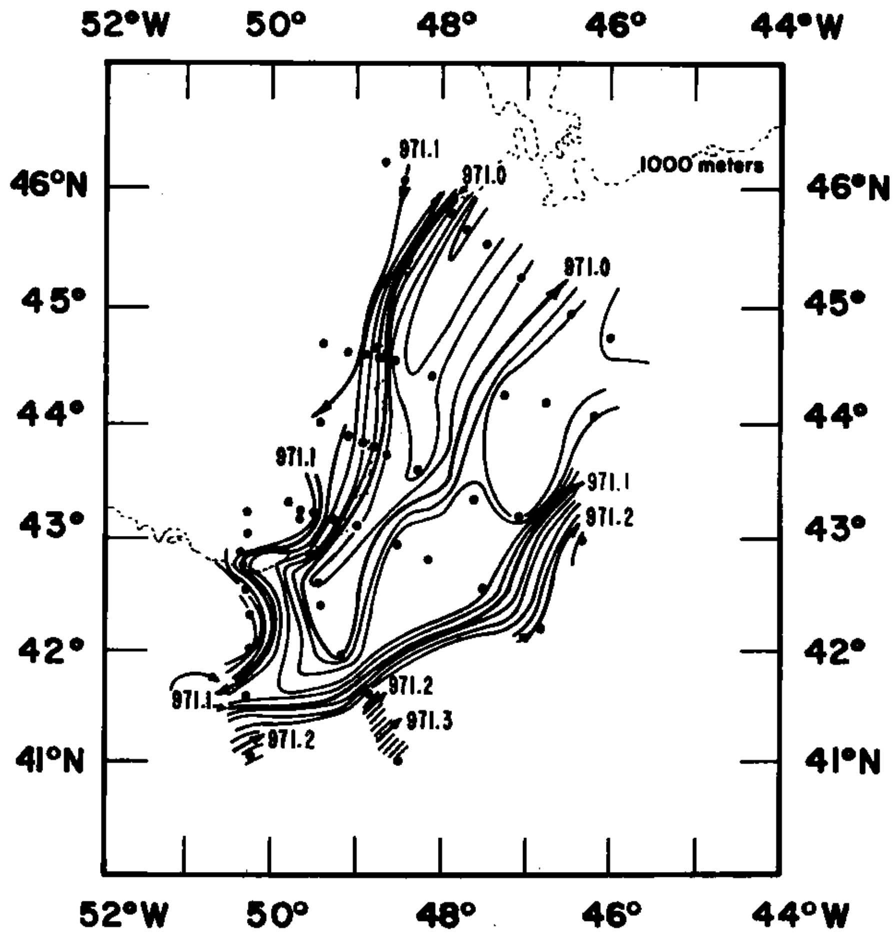

Fig. 18. May 1972 normal dynamic topography of the sea surface relative to the 1,000 dbar surface.

both currents. This area is referred to as the "trough". The same three features are present in the dynamic heights chart for April 1972 (Fig. 17). However, the Labrador Current is narrower and extends further south than normal, while the North Atlantic Current meanders are further west than usual.

The May "normal chart" is basically similar to the April chart, but as expected, the influence of the Labrador Current does not extend as far south as in April. The May 1972 dynamic heights chart (Fig. 18) is dramatically different from the May "normal." The Labrador Current is narrower than normal, but even more interesting is the large dynamically flat area centered around 42°50'N, 48°W. As this area has surface water temperatures in excess of 10°C, it seems probable that it was created from a meander which separated from the North Atlantic Current. To the west of this area, the Labrador Current curves westerly for a short distance prior to returning to a more normal course. The "normal chart" for June is similar to those of April and May. However, in June the Labrador Current is less well defined and its influence does not extend as far south as in the previous months.

Due to operational commitments, the June 1972 survey (Fig. 19) by the Coast Guard Cutter *Evergreen* was somewhat abbreviated. Even this late in the ice season, the Labrador Current was well defined and extended far south. There was no indication of westerly fluctuation that had been present in May. There was no sign of a large dynamically level area, however, the June survey only extended over part of this region. There is other information to support the theory that this level region had disappeared by the June survey.

On 15 May the Coast Guard Ice Patrol aircraft flew over the area in question on an ice reconnaissance flight. This was only 2 days prior to the May dynamic survey in this area. On this flight no icebergs were sighted in the dynamically level area. This could be expected because of the high water temperatures. The ice conditions broadcast by Commander International Ice Patrol 8 days later, indicated that this warm area no longer existed. In that broadcast, several icebergs were reported well within the area that had been occupied by the level area. Thus this condition had most likely disappeared prior to June.

Although the previous dynamic comparison may have proved interesting, the most significant information for the question at hand is obtaining by comparing 1972 current velocities with the normal velocities (Table 2). These values were obtained in each case from the swiftest portion of the Labrador Current as it crossed the indicated latitude. In every comparison the 1972 geostrophic velocity is greater than the normal. In fact, it is more than doubled in two cases. Although dynamic data is lacking for the portion of the Labrador Current off the Labrador coast, it is felt that similar comparisions would result there if data were available. This extraordinarily large velocity would markedly increase the efficiency at which icebergs were transported south. This decrease in transit time would also allow less deteriroation of the icebergs as they drifted south.

Therefore the effects of both wind and ocean currents, which are the two primary factors affecting the efficiency of iceberg transportation, were such as to favor a heavy ice year in 1972.

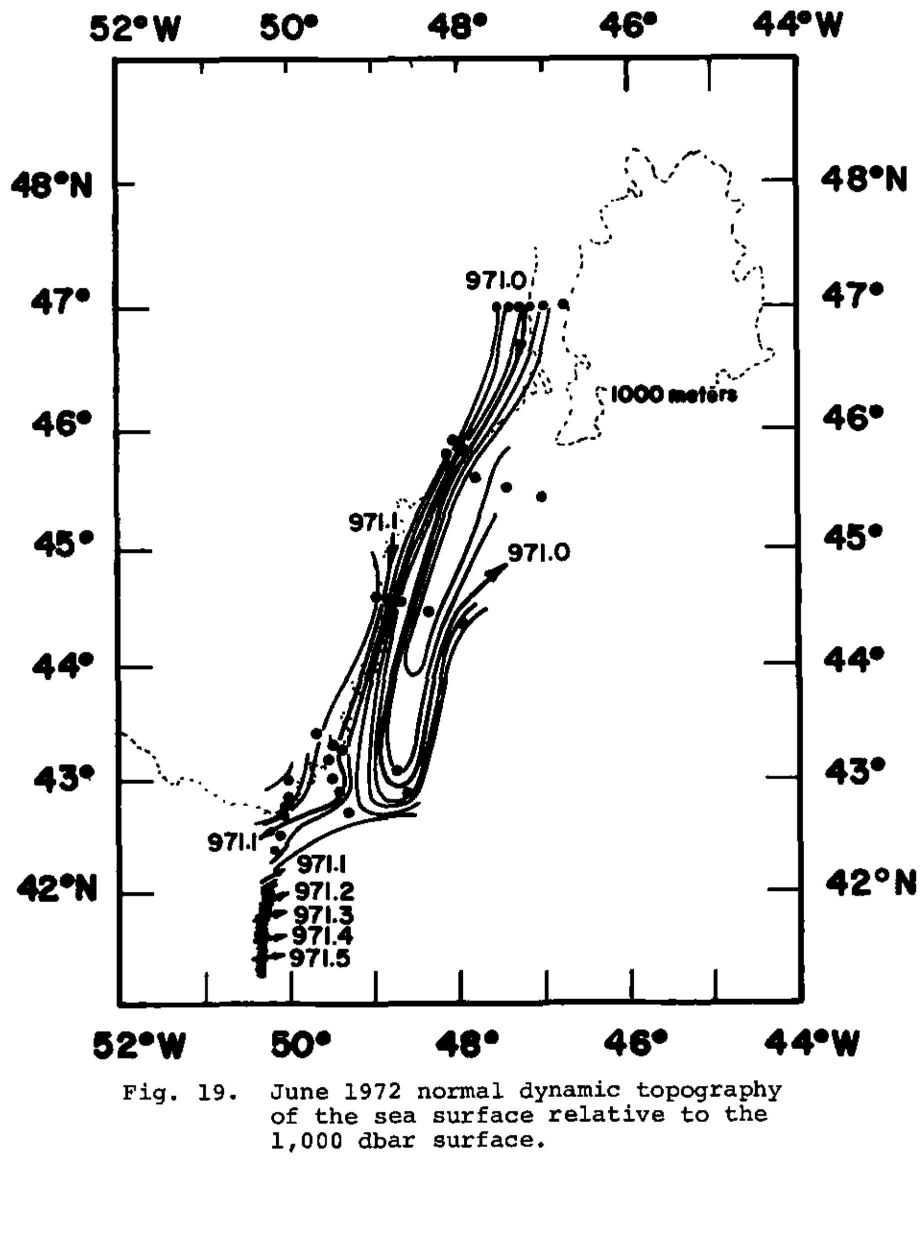

Fig. 19. June 1972 normal dynamic topography of the sea surface relative to the 1,000 dbar surface.

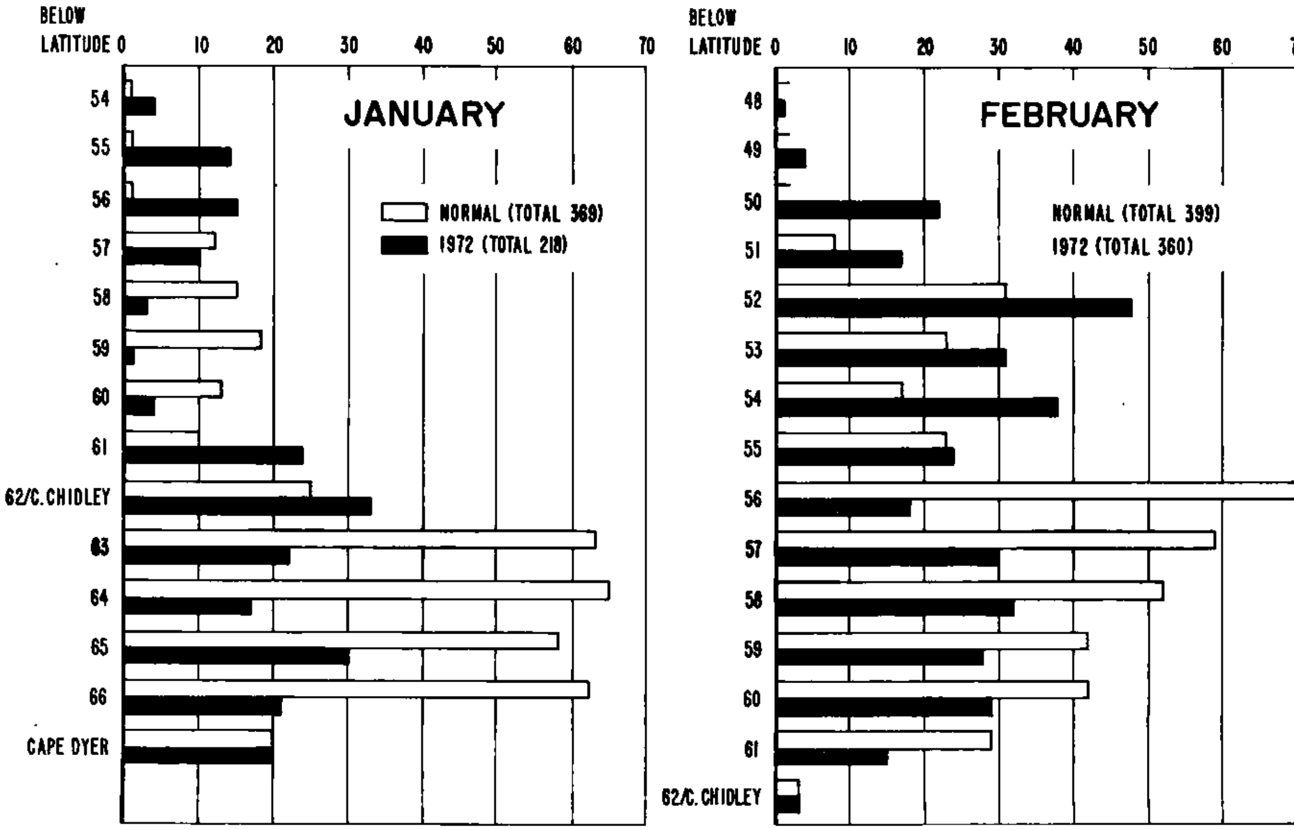

Fig. 20. Icebergs observed during pre-season Ice Patrol flights for 1972 and normal cases.

This leaves only one factor to be considered; supply of available icebergs. The icebergs that threaten shipping in the vicinity of the Grand Banks are calved from glaciers on the west coast of Greenland. After their formation, they generally move along the Greenland coast, move westward across Baffin Bay and then south along the Canadian coast. It may take an iceberg 3-5 years to reach the Grand Banks.

It is generally felt that the number of icebergs formed each year is basically constant. But as shown by Wolford (1972), the estimation of the number formed varies greatly. However, even the most conservative estimates indicate that more than 10 times more icebergs are formed annually than reach the Grand Banks. Some estimates are many times higher. This indicates that each year there are enough available icebergs to cause a severe iceberg threat.

Prior to the commencement of the official Ice Patrol season, iceberg reconnaissance flights were made by Coast Guard aircraft north of the area which is of the immediate interest to Ice Patrol. The purpose of these flights was to determine the number of icebergs along the Canadian coast which may drift into the Ice Patrol area during the upcoming ice season. From past experience, the January flight checked ice conditions as far north as Cape Dyer and the February flight only to Cape Chidley. Although the sightings from these flights seem somewhat surprising (Fig. 20) in view of the heavy ice season in 1972, a reasonable explanation is possible.

On the January flight, substantially fewer icebergs than normal were sighted. By February the count was almost normal. It is felt that this rapid increase to near normal iceberg count resulted from the lower mortality rate of icebergs and the high efficiency of transportation to the Grand Banks. Thus icebergs from an area much larger than normal were able to reach the Grand Banks.

In the majority of iceberg drift studies conducted by Ice Patrol (Wolford, 1972) over several years, most icebergs were found to advance 3-6 miles per day. However, in exceptional cases iceberg advances in excess of 20 nautical miles per day have been recorded. Thus, under the ideal conditions that existed in 1972, it is not unreasonable to assume that icebergs could have maintained a speed of advance of 0.5 kts for long periods of time. At this rate, icebergs near Cape Dyer could traverse the distance to the Grand Banks during the peak of the ice season (Fig. 21). Since the source of threatening icebergs was much larger than normal, it is believed that many more icebergs than normal were available. Also, because of the previously mentioned conditions, a larger than normal percentage of available icebergs reached the Grand Banks.

In conclusion, all the factors that have been considered: low water and air temperature, extensive sea ice coverage, favorable winds and currents, and an ample supply of icebergs contributed to make 1972 a record ice year. If any of the conditions had not been as favorable, the severity of the record ice season would have been greatly reduced.

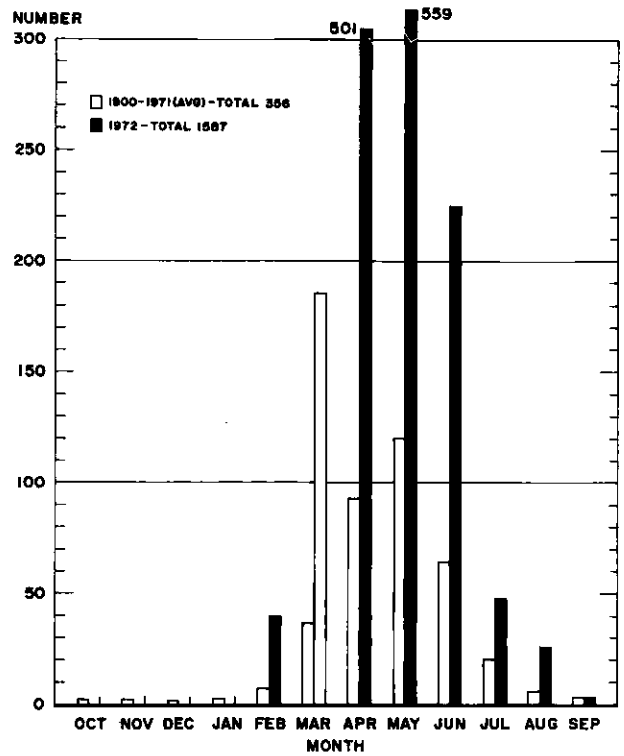

Fig. 21. Icebergs reported below 48°N for normal and 1972 cases.

TABLE 1. Monthly average temperatures and deviation from normal (°C) for four stations on the Canadian coast.

	April		May		June	
	Av9	Dev	Av9	Dev	Av9	Dev
Hopedale	-9.5	-4.4	-1.1	-2.8	5.0	-2.2
Cartwright	-7.2	-4.4	- .6	-3.9	7.8	-1.1
St. Anthony	-4.4	-3.3	0.0	-3.3	6.7	-1.1
St. John's	0.0	-1.1	5.0	- .6	15.0	4.4

TABLE 2. Comparison of normal and 1972 geostrophic velocities of the Labrador Current (cm/sec).

	Latitude	April	May	June
1972	45°N	37.1	34.8	34.2
Normal	45°N	30.8	24.7	21.3
1972	44°N	39.9	23.9	37.4
Normal	44°N	14.8	20.7	16.5

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The Continuous Plankton Recorder Survey: Plankton in the ICNAF Area in 1972

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INTRODUCTION

The survey by the Continuous Plankton Recorder (Hardy, 1939) was continued in 1972 on the same basis as in other years. Accounts of variation in abundance and distribution of the plankton in the northeastern Atlantic and the North Sea have been presented every year since 1946 in the ICES Annales Biologiques series. The survey was extended into the western Atlantic in 1959; an account of the routine data processing of results was presented to the General Meeting of ICNAF in 1973 (Robinson, Colebrook and Cooper, 1973) together with comments on the abundance and distribution of the plankton in 1971 in the ICNAF area.

METHOD

Continuous Plankton Recorders are towed at a depth of 10 m by merchant ships, Ocean Weather Ships and Coast Guard Cutters of the United States Navy once in each month along a number of standard routes (Fig. 1). The rolls of silk are cut into sections representing 10 miles of tow and alternate sections, bearing the plankton from 3 cubic metres of water, are analysed. The methods of analysis have been described by Rae (1952) and Colebrook (1960).

The area of the survey has been sub-divided into a grid of rectangles (each 1° of latitude by 2° of longitude) which are then grouped into larger areas; in this paper these larger areas correspond with ICNAF Subareas 1-5. The results for a few of the common species are shown in three different ways:

1. Charts of the average distribution of eleven taxa in 1972, together with anomaly charts for eight of them showing variations from the long-term mean distributions (Fig. 2-5).

2. A contoured matrix for ICNAF Subarea 3 showing the seasonal and annual variations

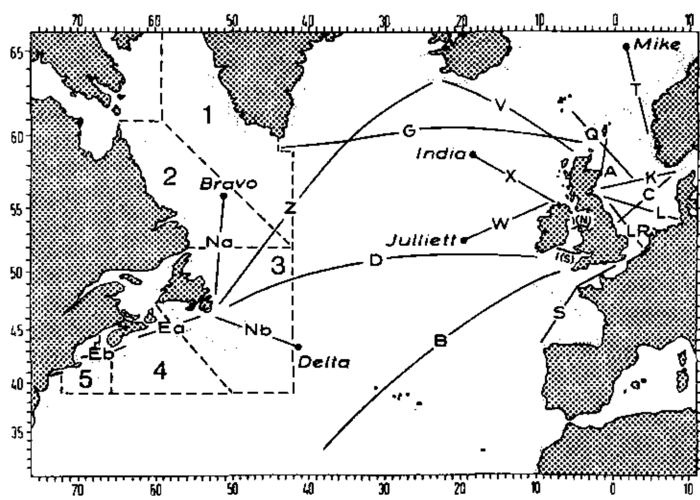

Fig. 1. The Continuous Plankton Recorder Survey during 1972. The routes are identified by code letters and the Ocean Weather Station by their international names. The boundries of ICNAF Subarea 1-5 are outlined.

of four major components of the plankton for every month from January 1961 to December 1973 (Fig. 6).

3. Histograms showing the seasonal cycle of abundance of nine taxa in each ICNAF Subarea in 1972, compared with the long-term average cycle for the period 1959-71 (Fig. 7-10).

Rectangle means, ICNAF Subarea means (monthly, annual and long-term) were calculated from logarithmic transformations of the original counts.

Information from other areas, and for species not illustrated here, will be supplied on application to the Director, Institute for Marine Environmental Research, Oceanographic Laboratory, Craighall Road, Edinburgh, EH6 4RQ, Scotland.

DISTRIBUTIONS

The charts in Fig. 2-5 give the average distributions in 1972 of the phytoplankton, the two major components of the zooplankton (Copepoda and Euphausiacea) and a selection of

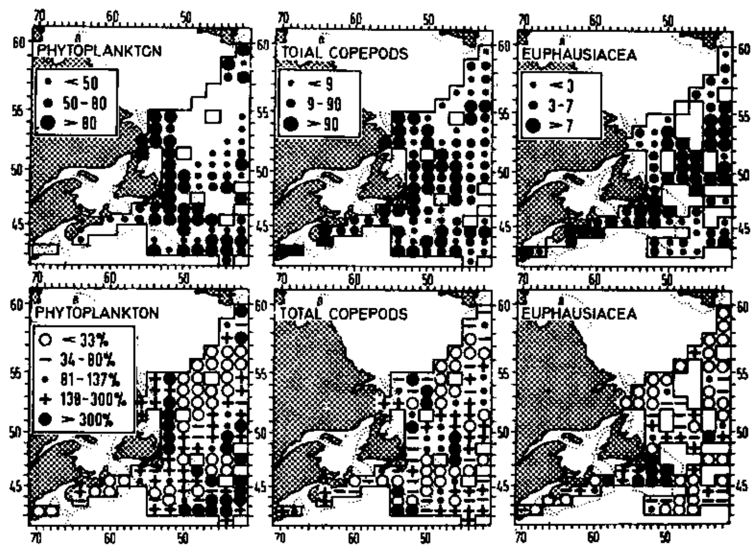

Fig. 2. Above charts showing the geographical distributions of phytoplankton total copepods and Euphausiacea in the ICNAF area in 1972. The symbols show the average number of organisms per sample for each statistical rectangle of 1° latitude by 2° longitude (see key at top left of each chart); the phytoplankton scale is an arbitrary measure of the green coloration of the samples. The distribution chart for Euphausiacea was constructed from samples taken at night only. Below, anomaly charts of the distribution of phytoplankton, total copepods and Euphausiacea for 1972. The symbols represent the average numbers per sample, expressed as a percentage of the 13 year mean (1959-71); Blank statistical rectangles in the anomaly charts indicate areas in which the organisms has not been found in CPR samples at any time from 1959 to 1972.

species which are either abundant or indicative of cold-water conditions in the ICNAF area.[1] The results are also expressed as anomalies from the long-term mean distribution during the previous 14 years. It should be borne in mind that variation in sampling from month to month creates 'noise' in the distribution charts when they are condensed to charts of annual distributions. This 'noise' is amplified in the anomaly charts when the distributions for one year are compared with distributions obtained from regular sampling over a long period.

The estimate of the phytoplankton (Fig. 2) was obtained from a visual assessment of the green coloration of the filtering silks. Phytoplankton was more abundant than usual in the waters of the Labrador Current and the area east and southeast of the Grand Banks; it was scarce in the Labrador Sea, and the coastal waters of Nova Scotia and the Gulf of Maine. The pattern of anomalies for Total Copepods (Fig. 2) was not so clear but numbers were below the long-term average in the waters south of Cape Farewell, over the Grand Banks and in the Laurentian Channel. Euphausiacea (Fig. 2) were more abundant than usual over, and to the northeast of, the Grand Banks but below average in all other parts of the ICNAF area surveyed by the Continuous Plankton Recorder.

The distribution of *Thalassiothrix longissima* (Fig. 3), a dominant member of the phytoplankton of the Northwest Atlantic, was unusually restricted but it was above average in those areas in which it did occur (Labrador Current and over the eastern edge and north-east of the Grand Banks). *Ceratium longipes* (Fig. 3) was scarce over much of the coastal and shallow water regions in which it usually occurs but there was a patch of higher numbers than usual over deeper water to the east of Newfoundland. However, *Ceratium arcticum* (Fig. 3), which normally occurs in cold water, was more abundant than usual in the northern part of the Grand Banks, over the deeper water northeast of the Grand Banks and close to the Nova Scotian coast. Except for isolated occurrences it did not penetrate as far south as in previous years.

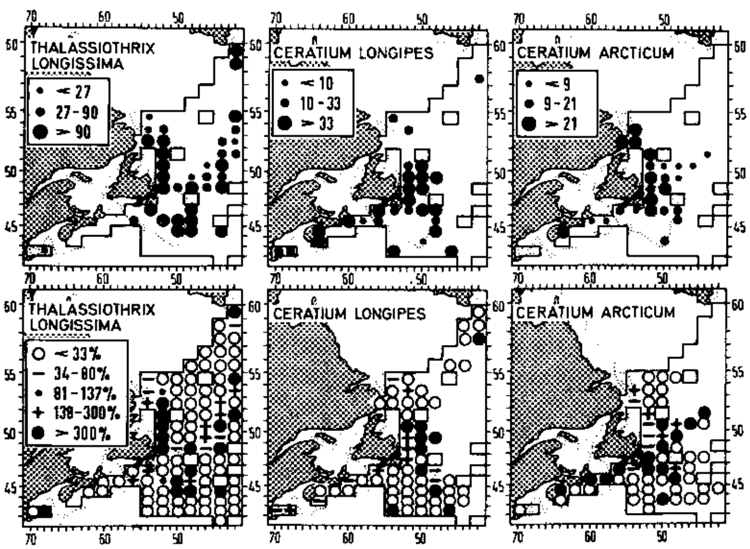

Fig. 3. Charts showing the geographical and anomaly distributions of *Thalassiothrix longissima*, *Ceratium longipes* and *Ceratium arcticum* in the ICNAF area for 1972. The numbers are given in thousands per sample. Blank statistical rectangles in the anomaly charts indicate areas in which the organism has not been found in CPR samples at any time from 1959 to 1972. For further details see legend for Figure 2.

[1] Average distributions of these entities in the North Atlantic for the period 1958-68 are given in Edinburgh, Oceanographic Laboratory (1973).

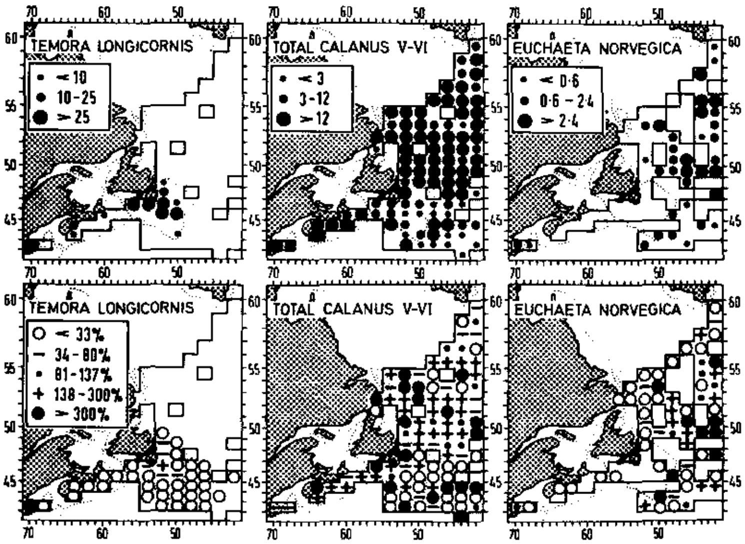

Fig. 4. Charts showing geographical and anomaly distributions of *Temora longicornis*, Total *Calanus* V-VI and *Euchaeta norvegica* in the ICNAF area for 1972. Blank statistical rectangles in the anomaly charts indicate areas in which the organism has not been found in CPR samples at any time from 1959 to 1972. For further details see legend for Fig. 2.

Temora longicornis (Fig. 4) in 1972 was confined, as usual, to the shallow water areas but it was much below average abundance. *Calanus* V-VI, mostly adult *Calanus finmarchicus* (Fig. 4), were below average in the south-eastern part of the survey area and south of Cape Farewell and above average in waters of the Labrador Current; elsewhere the pattern was not clear. The distribution of *Euchaeta norvegica* (Fig. 4) was calculated from night samples only, as this species carries out vigorous diurnal migrations. There was a region with higher numbers than usual over deep water in the easternmost part of the ICNAF area, with numbers lower than average south of Cape Farewell, southwest of the Grand Banks and in the westernmost part of its distribution.

Calanus hyperboreus, *Calanus finmarchicus glacialis* and *Metridia longa* (Fig. 5) are found in cold water but, as they are comparatively scarce in Recorder samples, it has not been possible to produce anomaly charts for these species; all of them occurred in more easterly and southerly positions than usual. In 1972, *C. hyperboreus* was found in a patch to the northwest of the Grand Banks and at two positions over the Nova Scotian Shelf; *C. finmarchicus glacialis* was found a little further north and west in the waters of the

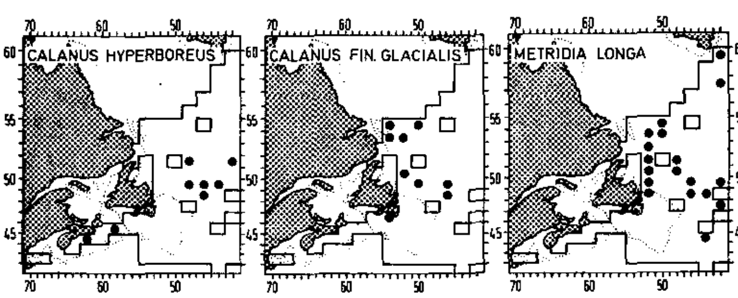

Fig. 5. Charts showing the occurrence of *Calanus hyperboreus*, *Calanus finmarchicus glacialis* and *Metridia longa* in the ICNAF area in 1972.

Labrador Current. *Metridia longa* was more widespread than the other two, but it was found mostly in the Labrador Current.

Annual and seasonal fluctuations in abundance

Figure 6 gives the annual and seasonal fluctuations in abundance for the twelve year period 1961-72 for phytoplankton, total copepods, copepodite stages V-VI and I-IV of *Calanus finmarchicus* for ICNAF Subarea 3. This is the area in which the CPR Survey gives the best sampling cover and these are the main components of the plankton, but similar data are available for other taxa and areas. This figure is a repeat of Fig. 2 in Robinson, Colebrook and Cooper (1973) with the addition of information for 1972. The seasonal cycles of phytoplankton and total copepods tend to be complementary; the one succeeding the other. There were marked variations in the beginning of the spring outbreak of phytoplankton, but no consistent trend within the 12-year period. However, the end of the spring outbreak occurred at a progressively earlier date from 1962 to 1968 and there was a similar but more marked trend in the seasonal start of production of copepods (from 1963 to 1969). From 1968 onwards there has been an autumnal outbreak of phytoplankton which was not apparent in other years, except briefly in 1964. The results for 1972 confirmed this trend and showed that the autumnal bloom has extended and increased. This may be related to changes in the abundance of copepods which, from 1967 onwards, became less common in the second half of the year especially.

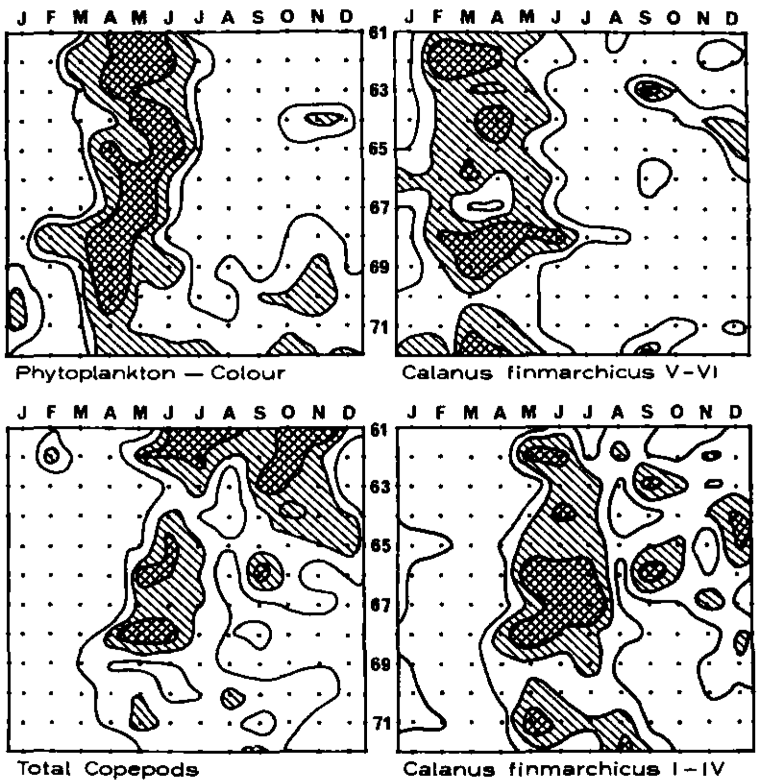

Fig. 6. Contour diagrams of the annual and seasonal fluctuations in abundance of phytoplankton, copepodite stages V-VI of *Calanus finmarchicus* total copepods and copepodite stages I-IV of *C. finmarchicus*. Contour levels for phytoplankton (green colour of silks) are shown on an arbitrary scale of 2, 4 and 6. Contour levels (back transformations, see p. 2) for the remaining diagrams are drawn at 10, 19 and 30 for *C. finmarchicus* V-VI, 250, 395 and 585 for Total Copepods and 42, 83 and 155 for *C. finmarchicus* I-IV.

The diagrams for copepodite stages V-VI and I-IV of *Calanus finmarchicus* should be compared. At the sampling depth of 10 m, the overwintering adult stages usually appear in February (and disappear in May or June) but they appeared occasionally in January (see, for example, 1966 and 1972). The time of production of copepodite stages I-IV showed the progressively earlier shift that was seen in the numbers of total copepods between 1963 and 1968 followed by a reversal of the trend (i.e. progressively later appearance of *Calanus* I-IV from 1969 to 1972). *Calanus* is the major component in the numerical estimates of copepods in Subarea 3.

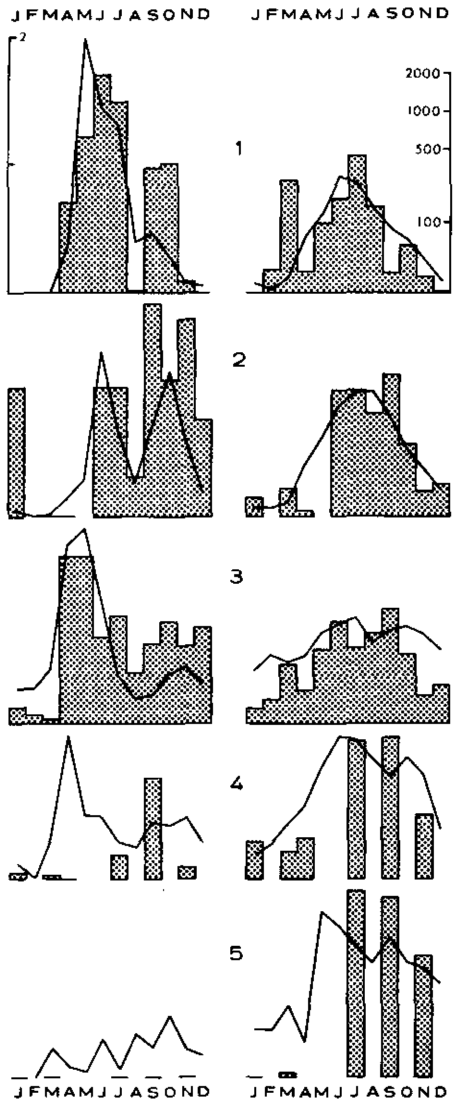

Fig. 7. Histograms showing average numbers per Recorder sample of phytoplankton (left) and total copepods (right) in ICNAF Subareas 1-5 in 1972. The line graphs show the mean value of the period 1959-71.

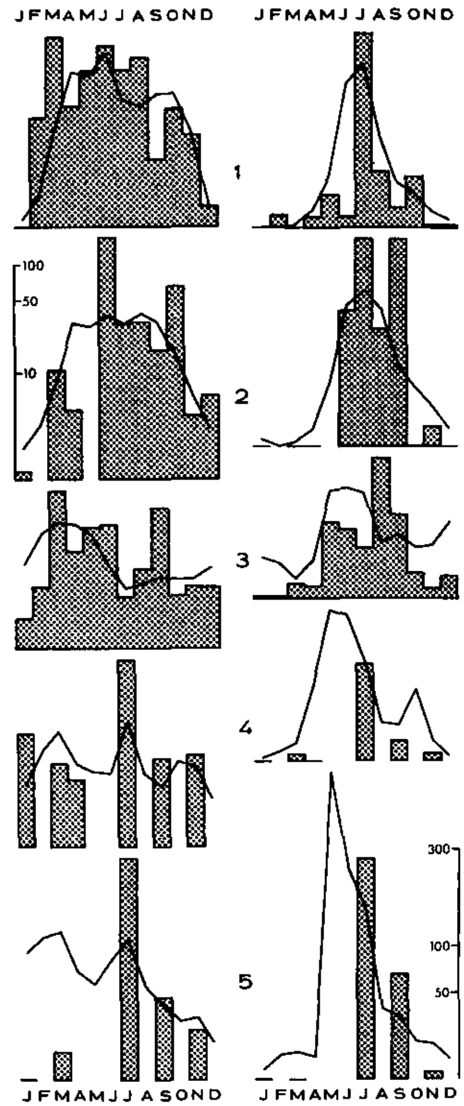

Fig. 8. Histograms showing average numbers of copepodite stages V-VI of *Calanus finmarchicus* (left) and stages I-IV of *C. finmarchicus* (right) in ICNAF Subareas 1-5 in 1972. The line graphs show the mean values for the period 1959-71.

Seasonal distribution in ICNAF Subareas 1-5 in 1972

The results are presented in the same way as those published annually in the ICES Annloles Biologiques Series (Glover, Colebrook and Robinson, 1962). For each month, for ICNAF Subareas 1-5, the mean number per Recorder sample (of $3m^3$) has been calculated for the dominant members of the plankton. The results are shown in Fig. 7-10 in which the data for 1972 are presented as histograms (gaps in the baseline indicate there was no sampling in that month). A measure of the average seasonal cycle is provided by line graphs of the average number per sample during the period 1959-71. For all except the young fish the monthly means for 1972 as well as those for the previous 13 years combined were calculated from logarithmic transformations of the original counts; for the young fish the means were calculated from untransformed data.

Subareas 1 and 3 were sampled during every month of the year, and Subarea 2 in every month except February and May but Subareas 4 and 5 were sampled only in 6 and 5 months respectively. During 1972 Recorders were towed 1,120 miles in Subarea 1, 2,166

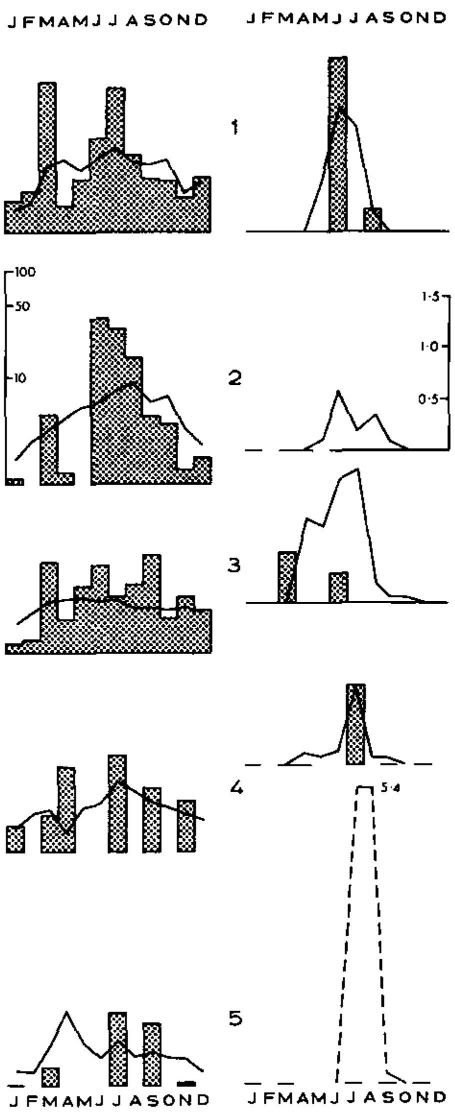

Fig. 9. Histograms showing average numbers per Recorder sample of Euphausiace (left) and young stages of *Sebastes* spp.[2] (right) in the ICNAF Subareas 1-5 in 1972. The line graphs show the mean values for the period 1959-71.

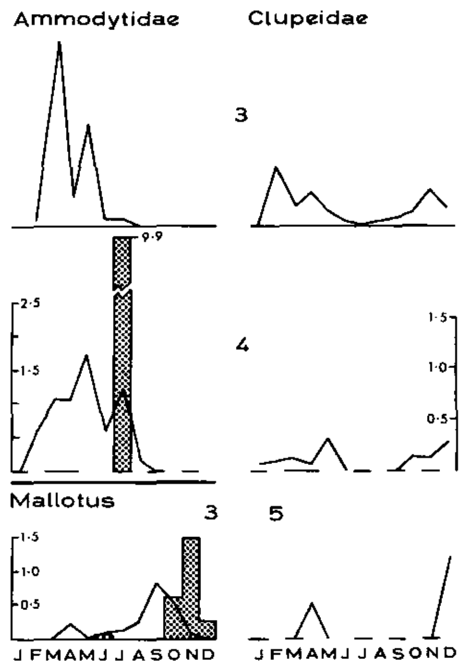

Fig. 10. Histograms showing average numbers per Recorder samples of young stages of Ammodytidae[2] in Subareas 3 and 4, Clupeidae[2] in Subareas 3, 4, and 5 and *Mallotus villosus*[2] in Subarea 3 in 1972. The line graphs show the mean values for the period 1959-71.

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[2] The numbers of young fish have been multiplied by ten in the figures.

miles in Subarea 2, 11,568 miles in Subarea 3, 2,477 miles in Subarea 4 and 530 miles in Subarea 5.

An estimate of the phytoplankton obtained from a visual assessment of the green coloration of the filtering silks is shown in Fig. 7 (left). In Subarea 1 the spring outbreak of phytoplankton occurred at the usual time but the seasonal maximum was in June, about a month late. The standing crop was unusually high in Subarea 2 in January, but there was no phytoplankton in the samples taken in March or April; it was below the long-term mean from January to March in Subarea 3, from January to April in Subarea 4 and absent in March, when samples were taken, in Subarea 5. Thus there is strong evidence that the spring outbreak was later than usual in four out of the five areas, and the summer peak later in the fifth area. In the autumn, on the other hand, phytoplankton was more abundant than usual in at least three of the five areas; in September and October in Subarea 1, September to December in Subarea 2, July to December in Subarea 3 (and September in Subarea 4).

Numbers of copepods (Fig. 7, right) were much higher than average in March in Subarea 1; however, they were lower than usual from April to June in Subarea 1, April in Subarea 2, January to May in Subarea 3 and March and April in Subarea 4, suggesting that the beginning of the seasonal cycle was later than normal (as with the phytoplankton) in these Subareas. For the remainder of the year numbers were close to the long-term average off Labrador (Subarea 2) but tended to be low in Subareas 1 and 3. In Subarea 5 (where phytoplankton was absent in all 5 months for which there were samples) copepods were abundant in July, September and November (the only months when samples were taken in the second half of the year).

Copepodite stages V and VI of *Calanus finmarchicus* (Fig. 8, left) were more numerous than usual in February and March in Subarea 1, and March in Subareas 2 and 3. They were below average in all areas sampled in April, but thereafter, were abundant everywhere from May to October except for September in Subareas 1 and 2 and July and October in Subarea 3. They were particularly abundant in Subareas 4 and 5 in July.

Copepodite stages I-IV of *Calanus finmarchicus* (Fig. 8, right) were late in appearing in all Subareas, but peak numbers appeared at about the usual time in Subareas 1 and 2. In Subarea 3 numbers remained low, except for a brief peak in August and September, and below average in all months when samples were taken in Subarea 4, but abundant in Subarea 5 in July and September.

Euphausiacea, mostly *Thysanoessa longicaudata*, (Fig. 9, left) were more abundant than usual in March and from June to August in Subareas 1 and 2. Numbers were also above average in March and from May to September over the Grand Banks (Subarea 3) and during every month sampled from April onwards in Subareas 4 and 5; in these areas *T. raschii* and *T. inermis* were the dominant species.

Numbers of young stages of *Sebastes* (Fig. 9, right) were high in June in Subarea 1, March in Subarea 3 and July in Subarea 4. They were unusually scarce or absent in other months. Young stages of Ammodytidae (Fig. 10), which usually occur regularly in Subareas 3 and 4, were found only in July in Subarea 4, when numbers were much above average. Young stages of Clupeidae (Fig. 10) were absent from all samples taken in Subareas 3, 4 and 5 (and, as always, in Subareas 1 and 2), while *Mallotus* larvae (Fig. 10) were scarce, or absent, for much of the year in Subarea 3 and reached peak numbers two months later than usual (November instead of September).

Thus we may conclude that:

a) Phytoplankton was more abundant than usual in the waters of the Labrador Current and the sea areas east and southeast of the Grand Banks. The spring outbreak was late and persisted over the Grand Banks until July. The seasonal outbreak of copepods was also later than usual and numbers were particularly low over the Grand Banks. The time of production of total copepods (mostly copepodite stages I-IV of *Calanus finmarchicus*) has become progressively later since 1969 and this trend was continued in 1972.

b) Three cold water species, *Calanus hyperboreus*, *Calanus finmarchicus glacialis* and *Metridia longa*, were found in more southerly and easterly positions than in recent years, while *Euchaeta norvegica* was above average in the easternmost part of the ICNAF area.

c) Young stages of *Sebastes* and Ammodytidae were scarce for most of the year in most areas while Clupeidae were absent from all samples; *Mallotus* larvae were abundant over the Grand Banks 2 months later than usual.

ACKNOWLEDGEMENTS

We acknowledge gratefully the assistance of the captains and crews of many vessels which towed Continuous Plankton Recorders; the survey would be impossible without their willing co-operation. The plankton samples have been analysed by the staff of the Oceanographic Laboratory.

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Other Relevant Papers

The following three papers were submitted to the 1974 ICNAF Annual Meeting as Research Documents. However, the documents were clearly relevant to the proceedings of the Environmental Symposium and were considered during the discussions after the formal presentations. Hence they are included in this report for completeness.

Water Temperatures in the Nova Scotia Shelf and Georges Bank Areas, 1960-68

By V. A. Bryantsev,
Atlantic Research Institute of Marine Fisheries and Oceanography (AtlantNIRO),
Kaliningrad, USSR

Data on water temperatures were summarized from 10,287 hydrological stations occupied in 1960-68 during AtlantNIRO expeditions over the Nova Scotia Shelf and Georges Bank. Mean values of water temperature at three typical points on the temperature profile curve which reflects the variability of water temperature by depth (A or B, C and D of Fig. 1) and by months of the calendar year were determined for each one degree square (Fig.2-13). Each point represents a typical temperature for three layers: surface, intermediate and bottom, or for the three main water masses: inshore, Labrador and bottom, as described earlier (Bryantsev, 1965). In addition to mean values, the minimum and maximum values at the points for the period under study are given. The squares are numbered by latitude from the east to the west and by longitude from the north to the south and extend to include the 200-m isobath and greater depths in the deep waters of the Gulf of Maine and the Nova Scotia Shelf, which are not shown on Fig. 2-13.

The surface temperature, which changes from winter to summer, in the interval between A and B (Fig. 1), is characteristic of the inshore water mass (surface layer).

The Labrador water mass is characterized by the value of an intermediate temperature minimum (C). In winter (the B, C, D curve) the intermediate temperature minimum is absent as a rule, because both layers intermingle as a result of convectional mixing. In the transition periods, that is in spring and autumn, or in the regions where the intermediate temperature minimum is marked even in winter, the value at C was accepted only in cases when C was found below 50 m.

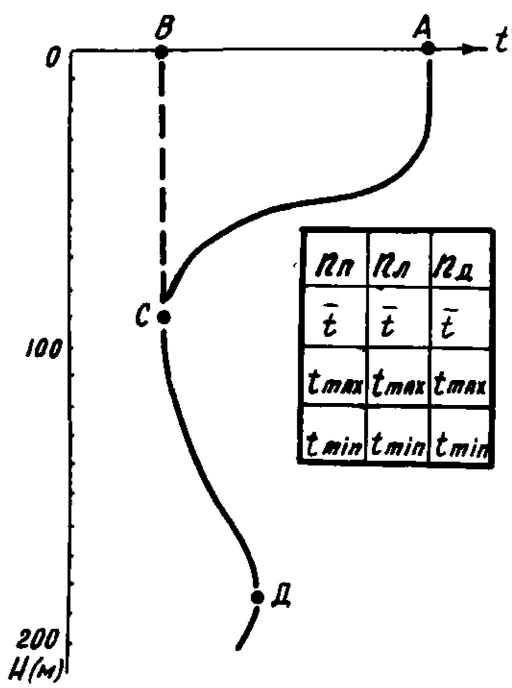

Fig. 1. Vertical temperature profile showing points representative of surface and inshore (A and B), intermediate or Labrador (C), and bottom or oceanic (D) water masses.

An intermediate temperature maximum (D) characterizes warm bottom water of oceanic origin. When it is absent, as, for example, at depths of less than 150 m, only the values for the bottom layer were chosen, provided that the inversion was revealed in the vertical distribution or the depth was above 90 m.

All values in the squares on the charts are arranged in the following order (Fig. 1): three columns represent the temperature values for the three water masses from left to right – inshore, Labrador and bottom. The upper figures show the number of chosen temperatures values (n) followed by their mean value ($\bar{t}$), maximum (t max) and minimum (t min). The empty squares have no observations or their number for the period of the studies was less than 10.

The values in the squares give some idea of the curve of mean and extreme temperature changes by depth in different areas for certain months.

The most numerous values of surface temperature may serve as a standard for estimation of thermal conditions for years, seasons and

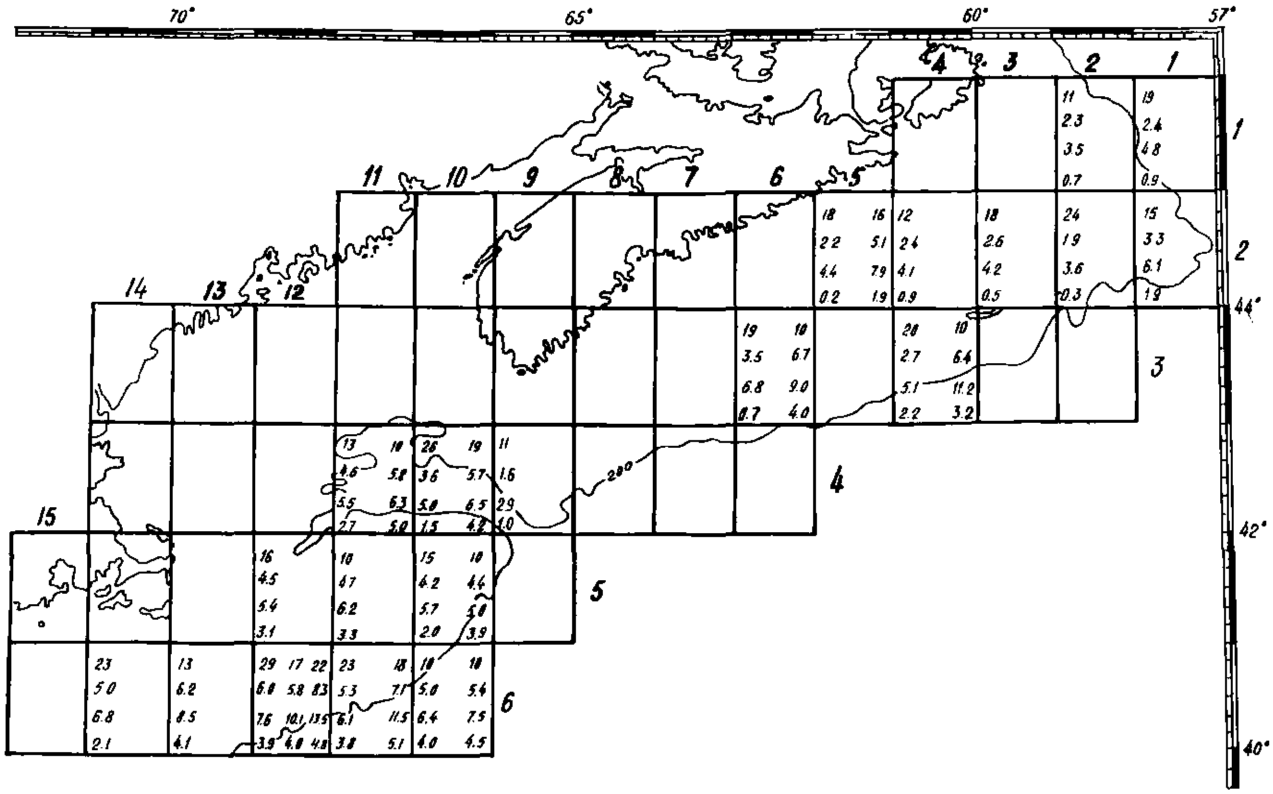

Fig. 2. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in January.

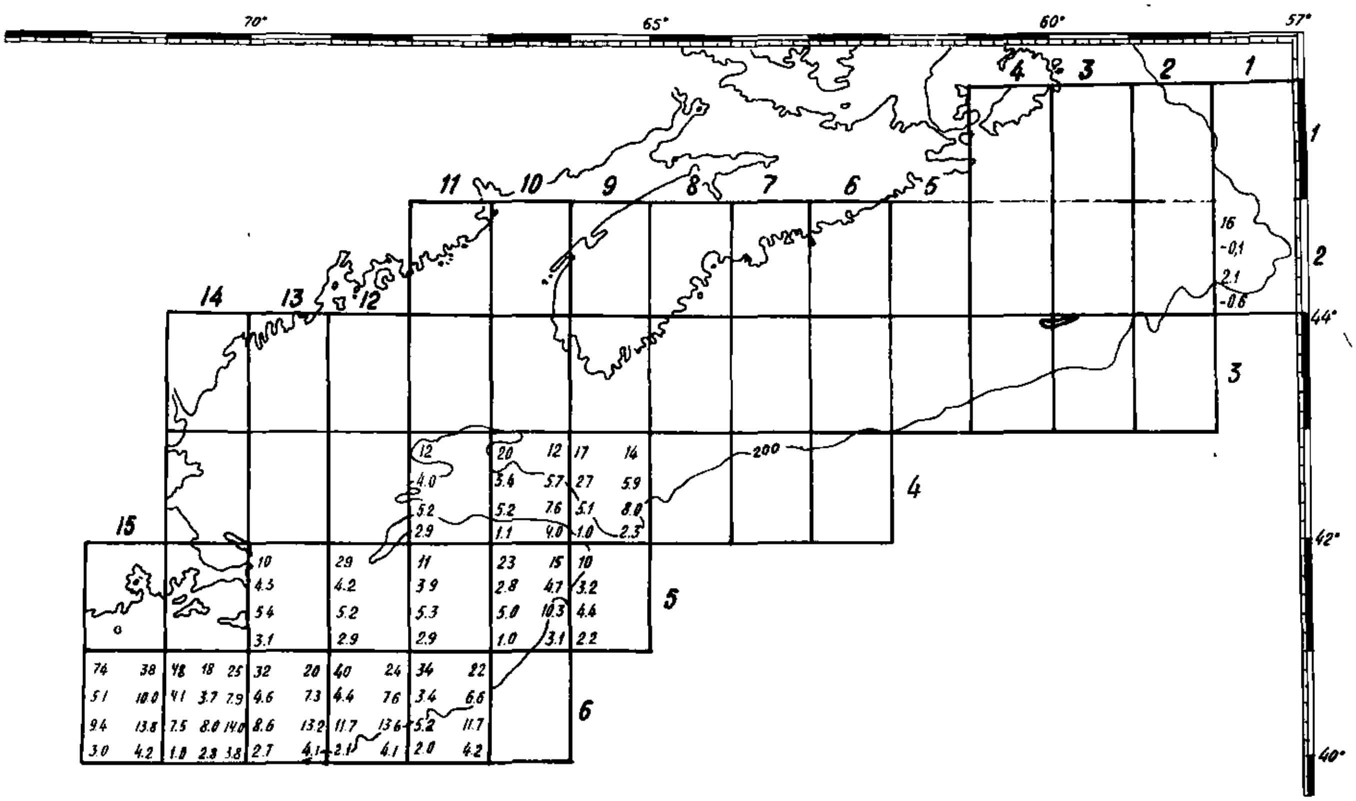

Fig. 3. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in February.

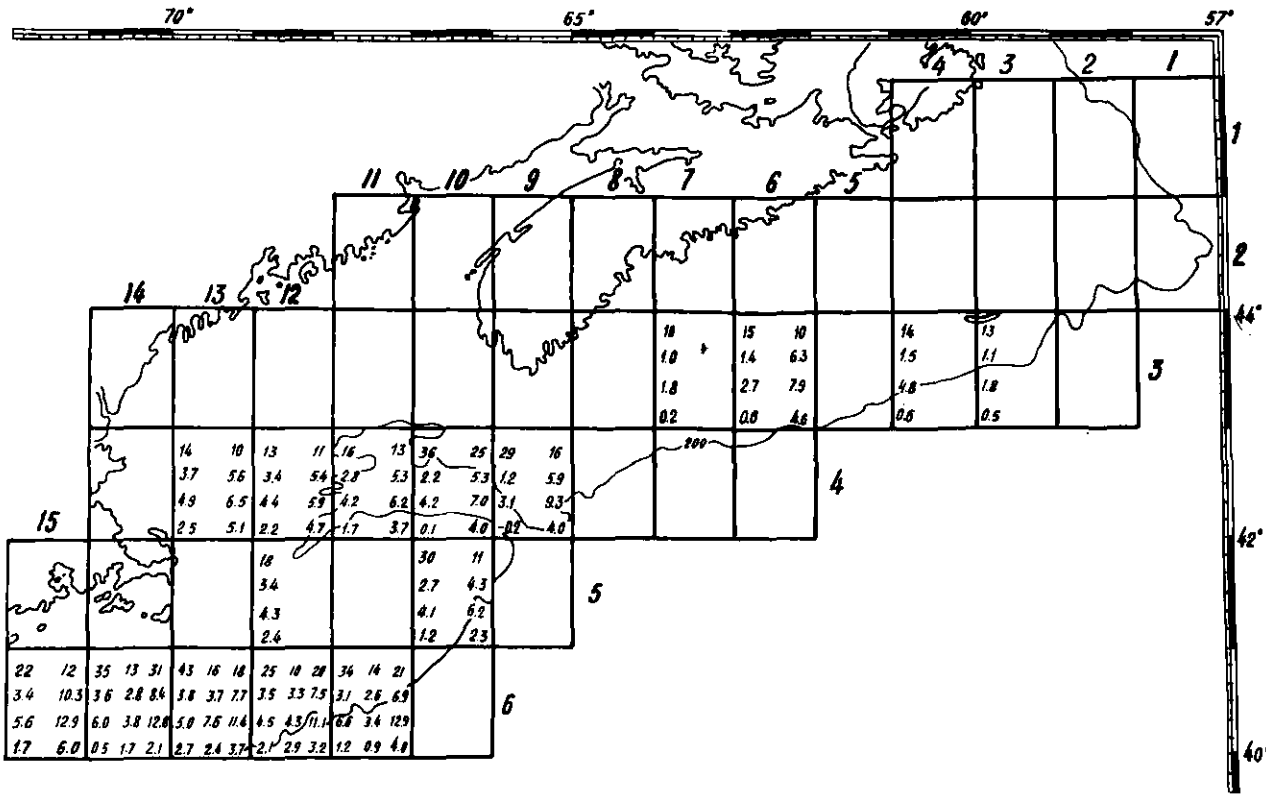

Fig. 4. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in March.

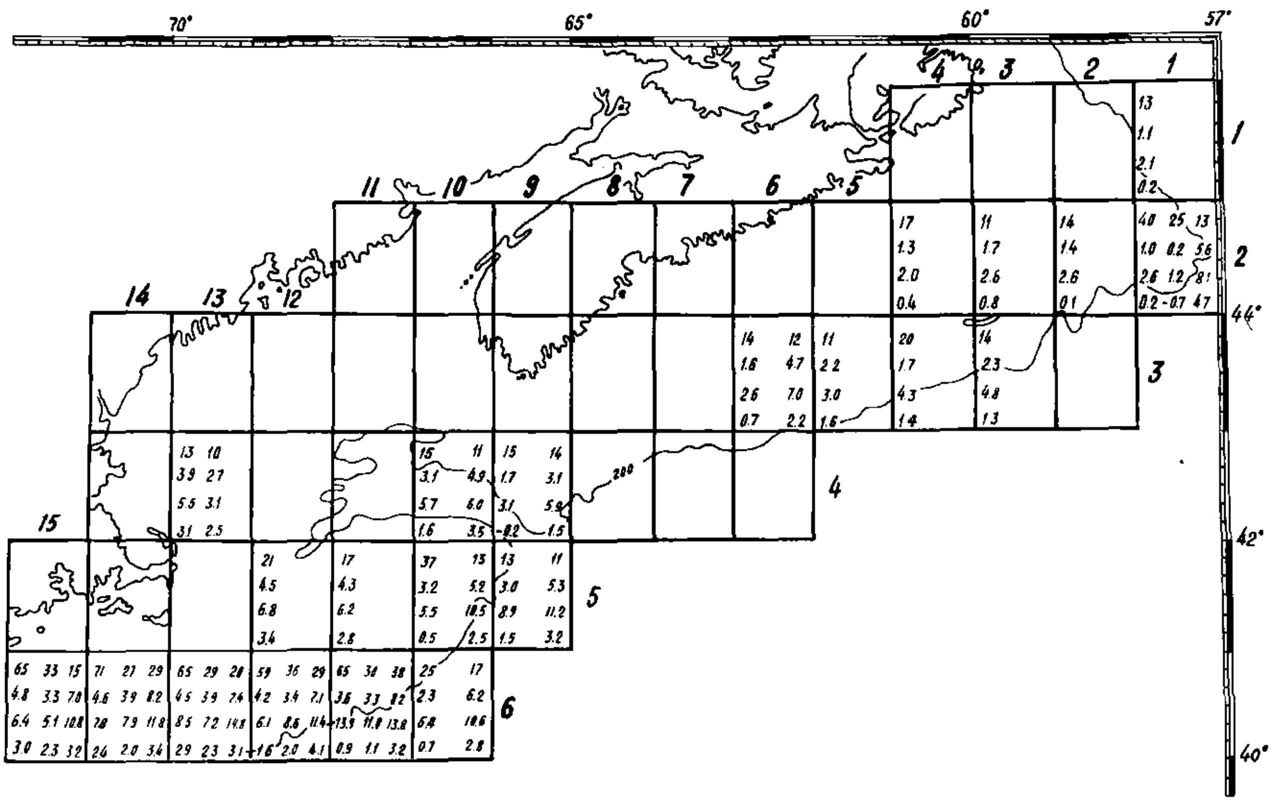

Fig. 5. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in April.

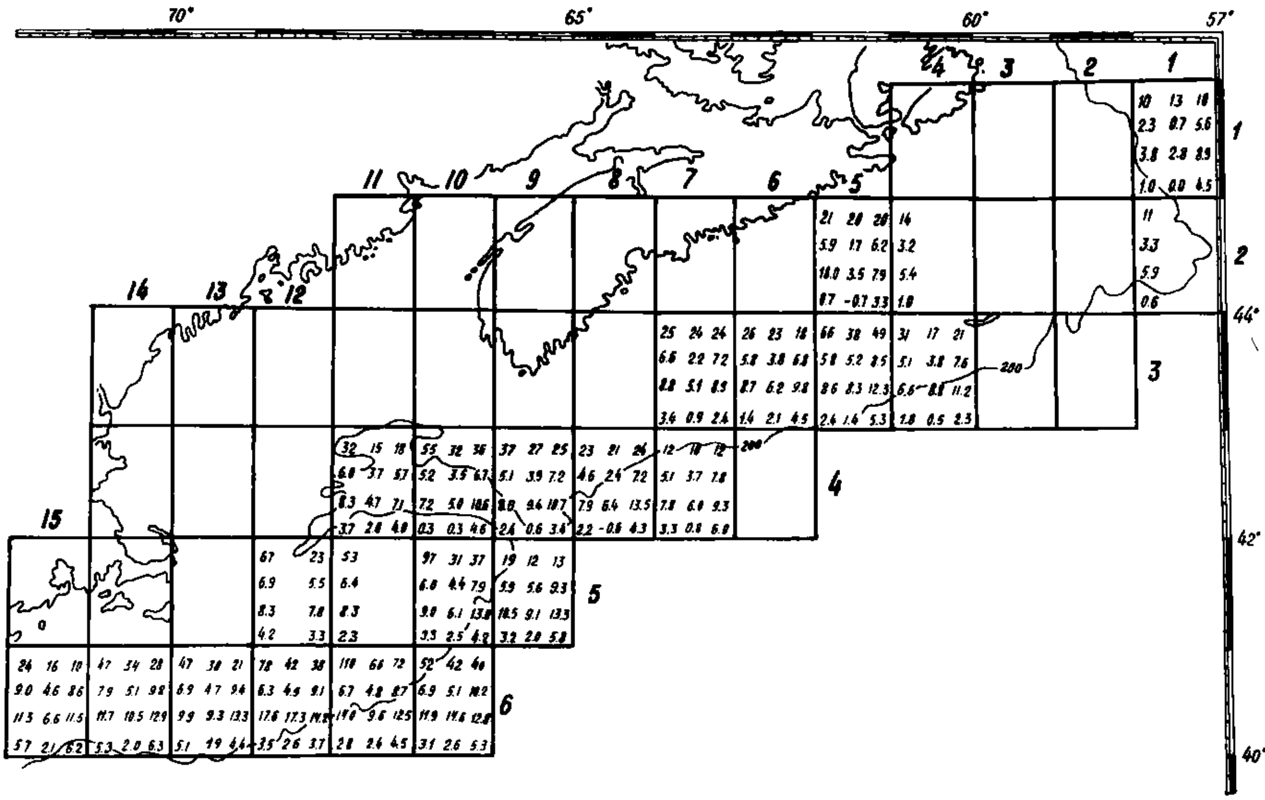

Fig. 6. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in May.

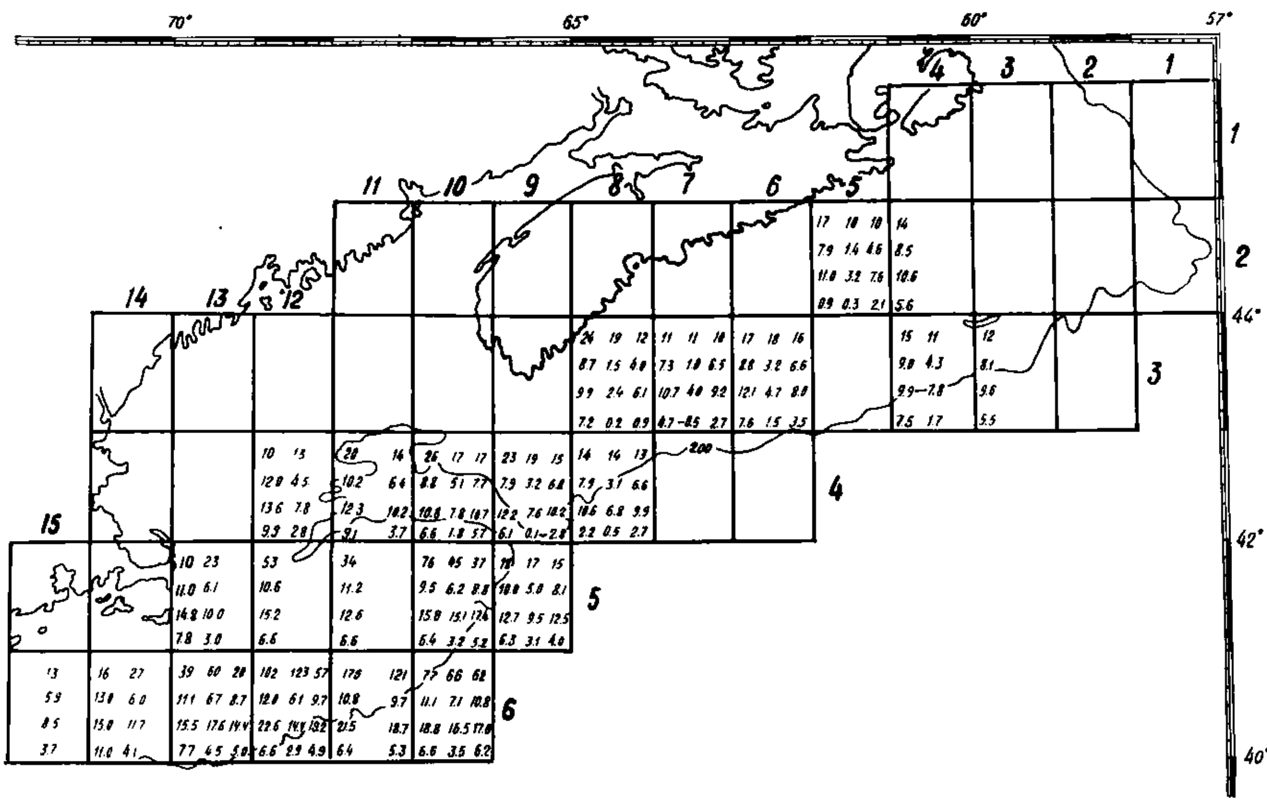

Fig. 7. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in June.

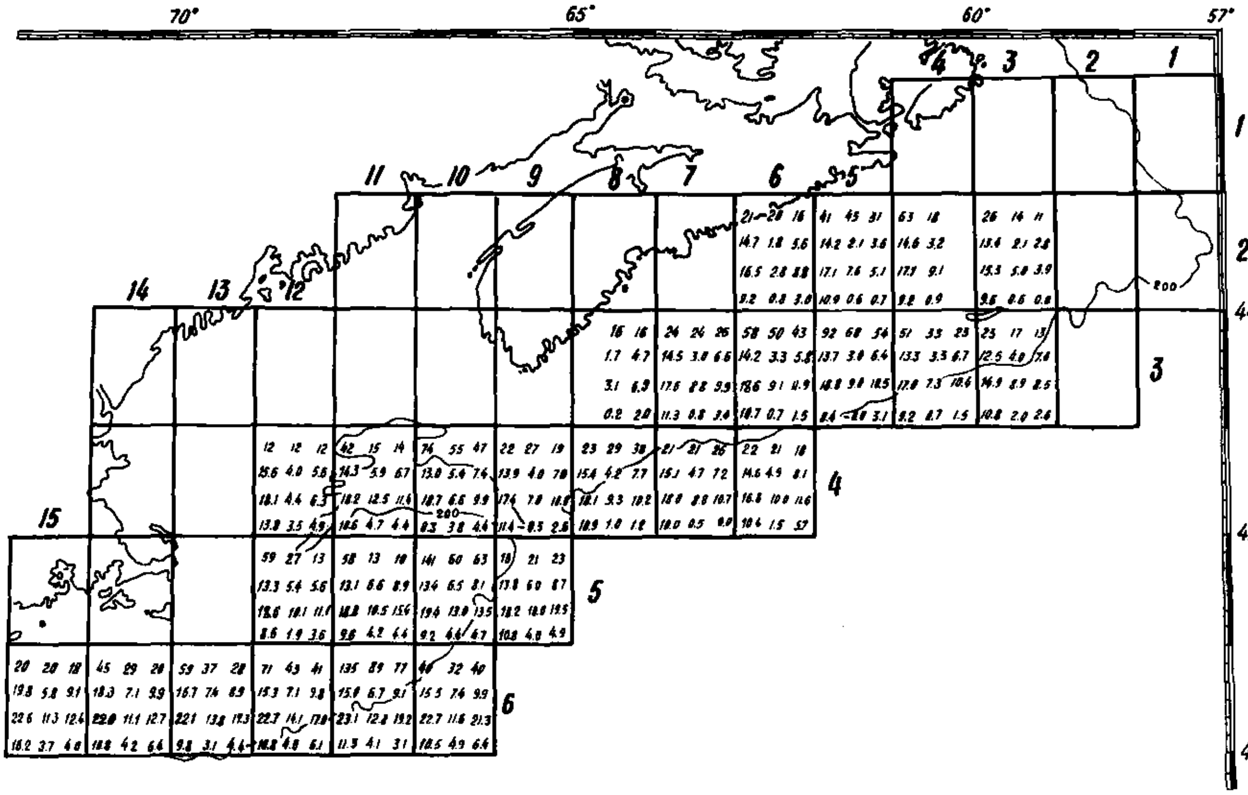

Fig. 8. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in July.

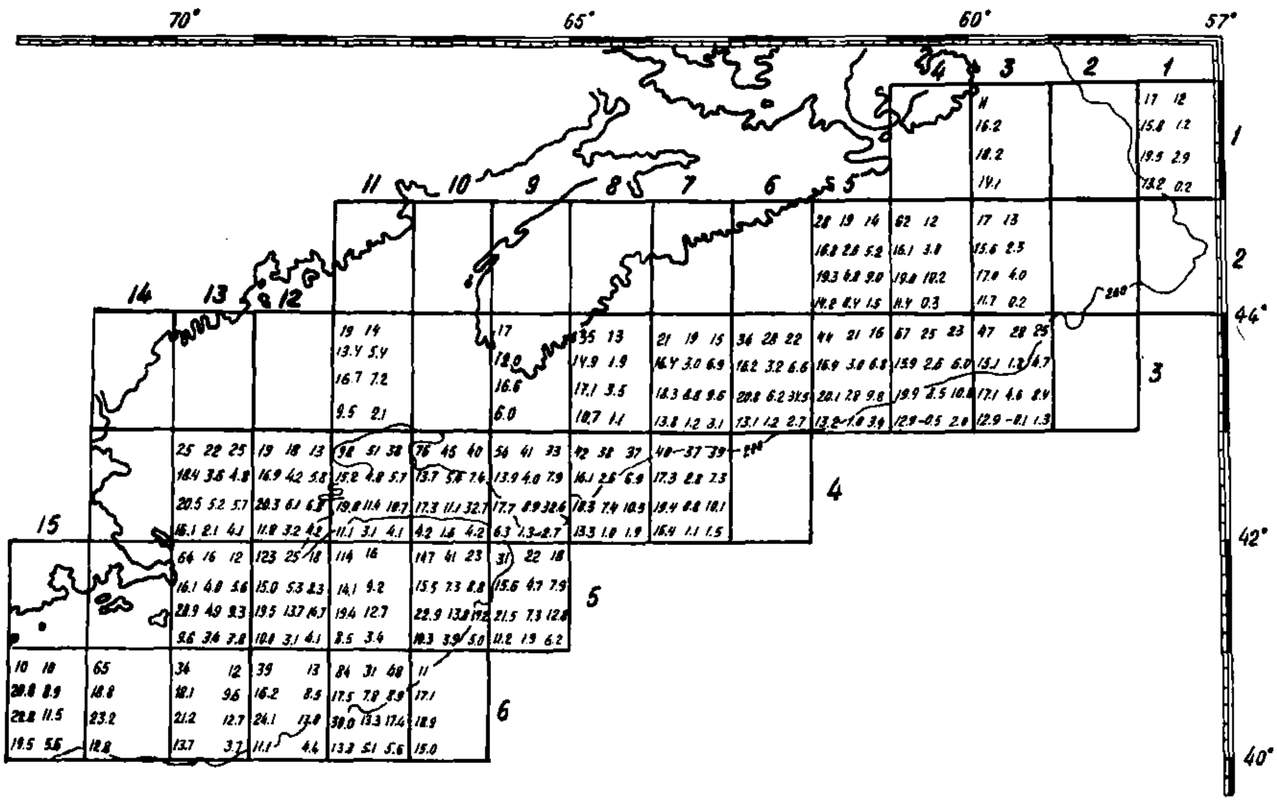

Fig. 9. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in August.

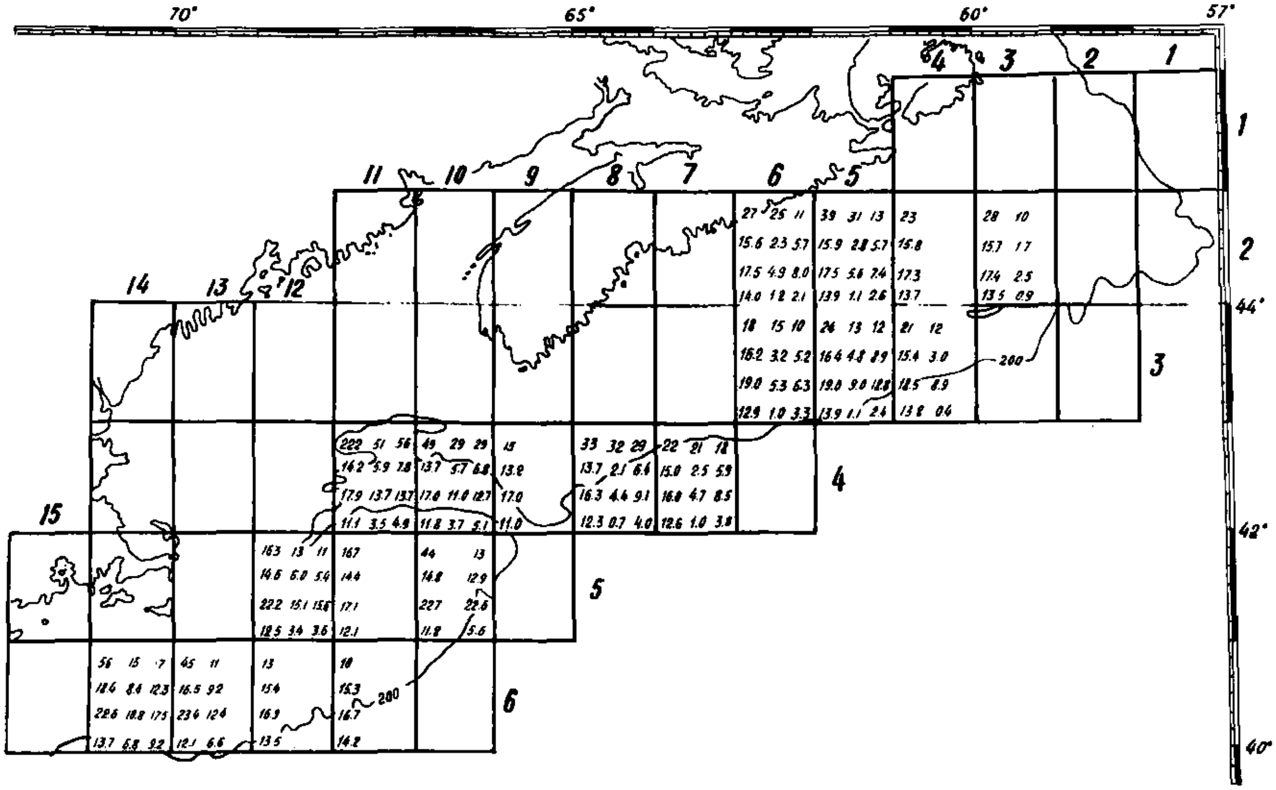

Fig. 10. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in September.

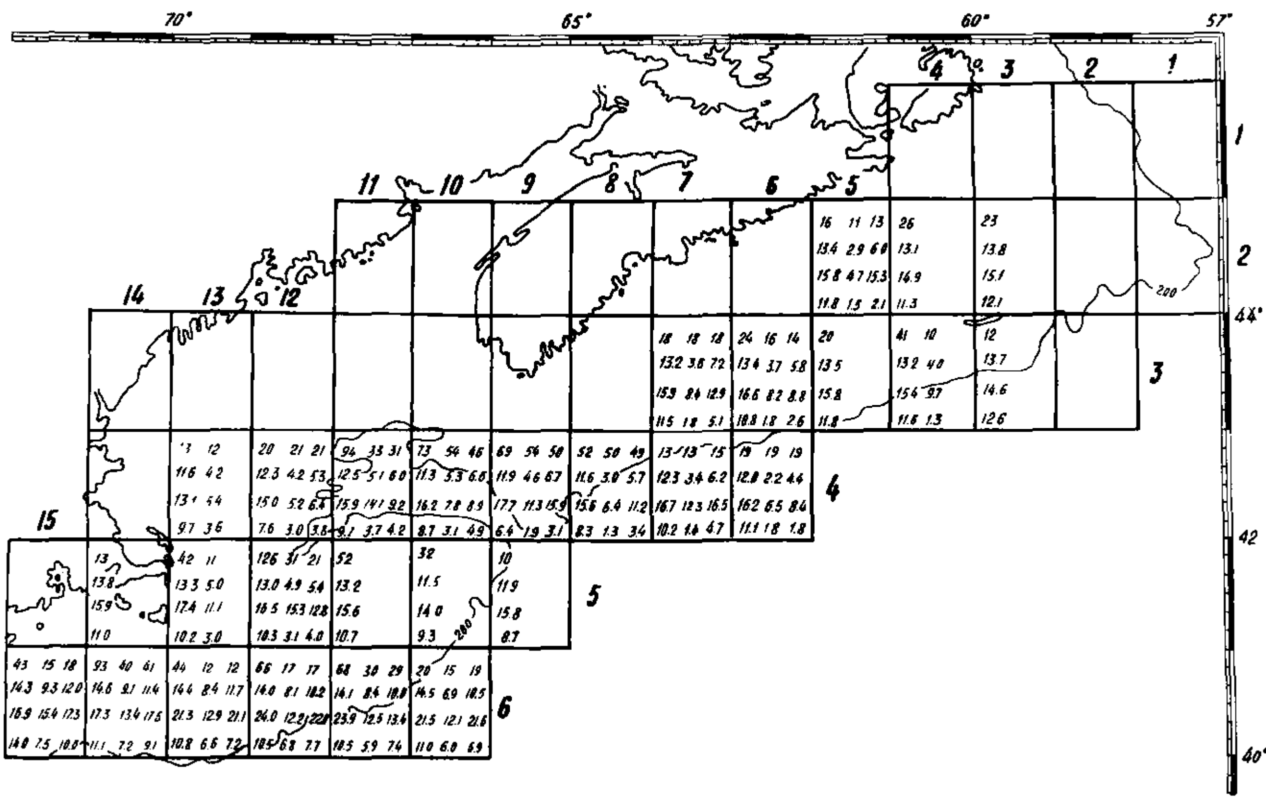

Fig. 11. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in October.

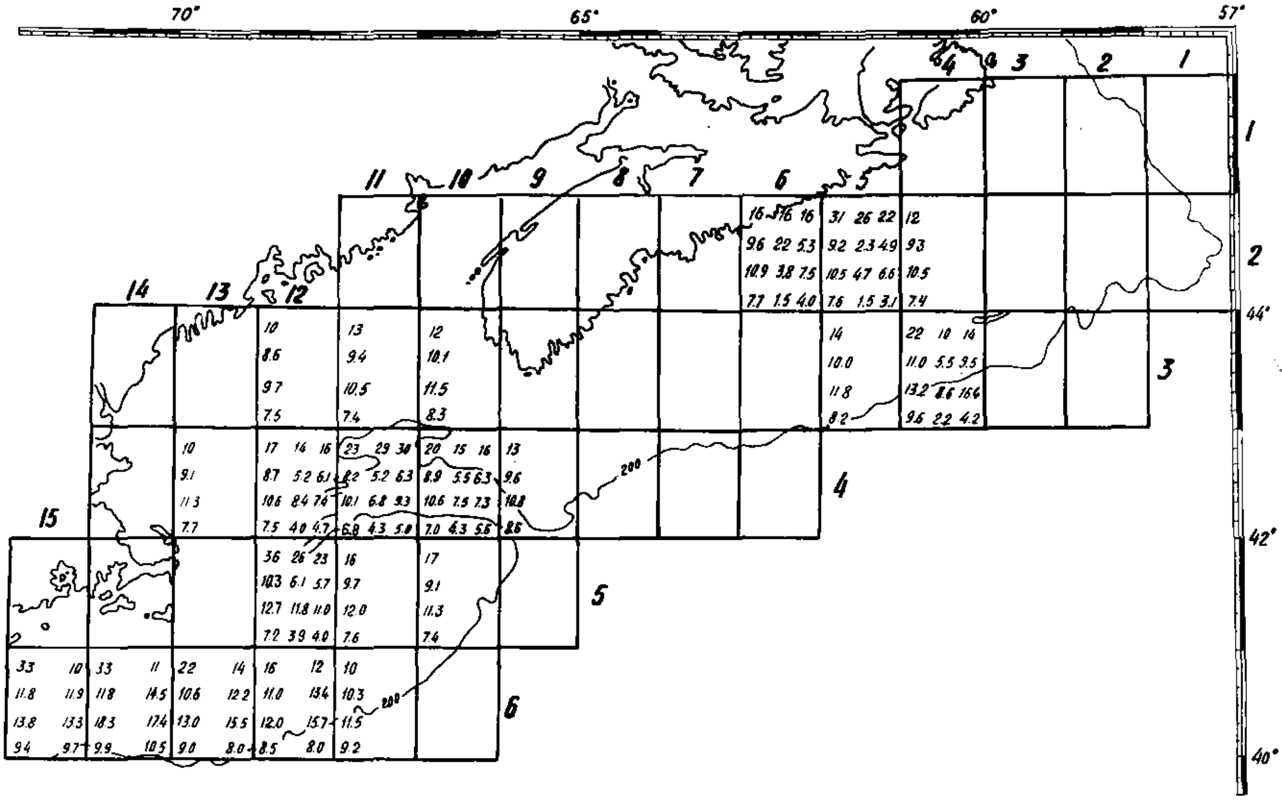

Fig. 12. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in November.

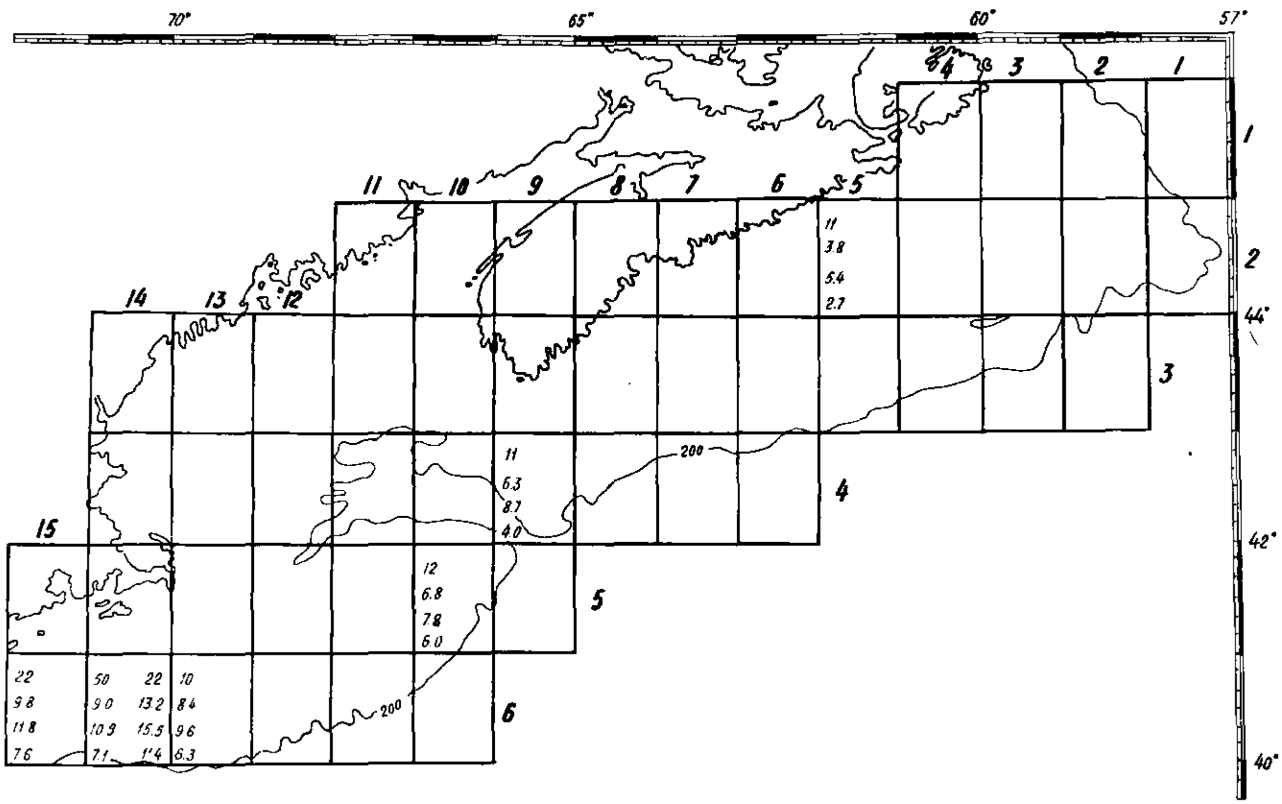

Fig. 13. Average maximum and minimum water temperatures of the inshore, Labrador and bottom water masses over one degree squares of the Nova Scotia and Georges Bank areas in December.

months over definite areas. Also, they may be useful in analyses of seasonal temperature variability in different areas, etc.

Reference

BRYANTSEV, V.A. 1965. The influence of water masses of the New England and Nova Scotia Shelf on the formation of commercial concentrations of herring. *Spec. Publ. int. Comm. Northw. Atlant. Fish.* No. 6, p. 597-602.

Characteristic Features of the Hydrological Conditions on the Nova Scotia Shelf and Georges Bank, 1972

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Introduction

The hydrological conditions in the area of Nova Scotia and Georges Bank in 1972 were characterized by a number of peculiar features as compared with the previous years. These peculiarities, mainly temperature variations, were likely to influence the behaviour and distribution of some commercial species. In particular, abudnant concentrations of young herring on the Nova Scotia Shelf in the winter of 1972 can be related to the abnormal hydrological conditions in the winter period. The paper deals with the characteristic features of the water temperatures in the winter and summer-autumn periods in 1972 based on the analysis of observations of water temperatures made by RTM *Bakhchisarai* in January-March and by R/V *Argus* in June-October in the above mentioned areas.

Materials and Methods

The character of the water temperature observations made by RTM *Bakhchisarai* and R/V *Argus* was different. The observations by *Bakhchisarai* were made episodically in parts of the area when searching for commercial concentrations of fish to determine the optimum fishing grounds and also on some standard sections. Water temperature observations during the cruise by R/V *Argus* were made in the period of ecological surveys on Georges Bank and parallel sampling for salinity, phosphates, nitrites, silicon, oxidability, oxygen and plankton, zooplankton and ichthyoplankton. Sixteen surveys were made during the cruise. However, the analysis of water temperatures was based upon the data from three surveys which covered the whole of Georges Bank in June, August and October. These surveys were made according to three different schemes. The June survey was carried out at stations obtained using a table of random numbers. The August survey was made over standard hydrological sections adopted by AtlantNIRO. The October survey was carried out over the stations adopted by ICNAF to determine the abundance of herring larvae.

The character of hydrological conditions in January-March is evident from *Bakhchisarai* observations without additional analysis of the data from the cruise report. The results obtained by R/V *Argus* in 1972 were compared with the observations made in June, August and October 1971 both on the basis of water temperatures averaged for different parts of Georges Bank in June and October and averaged by standard sections and layers in August (Fig. 1). As can be seen from Fig. 1, the averaging was based upon the data collected on the Shelf between 74° and 70°N, 70° and 68°N, and 68° and 66°N, as well as in the northern and southern parts of Georges Bank separately.

Results

Observations on the Nova Scotia Shelf made by RTM *Bakhchisarai* revealed a decrease in water temperatures in January over the whole eastern part of the Shelf as a result of an intensive inflow of surface water from Cabot Strait. Water temperatures in 0-100 m layer ranged from 0.5°C (near Cape Breton) to 2.5°C (along the edge of the Shelf). The 0°C isotherm extended along the eastern and southern slopes of Banquereau. In 1972 water temperatures over the whole area were lower than in 1971, especially in the southern part. By the end of January further southwesterly movement of cold water onto the area of Sable and Emerald Banks was observed and became more intensive after mid February. According to observations made early in March, the movement resulted in further cooling within the 0-100 m layer where the temperatures dropped below zero. Negative temperatures were characteristic of the Canso, Misaine and Artimon Bank areas (Fig. 2). The position of the 0°C isotherm in March was very close to the 200 m isobath from Cabot Strait to Galli.

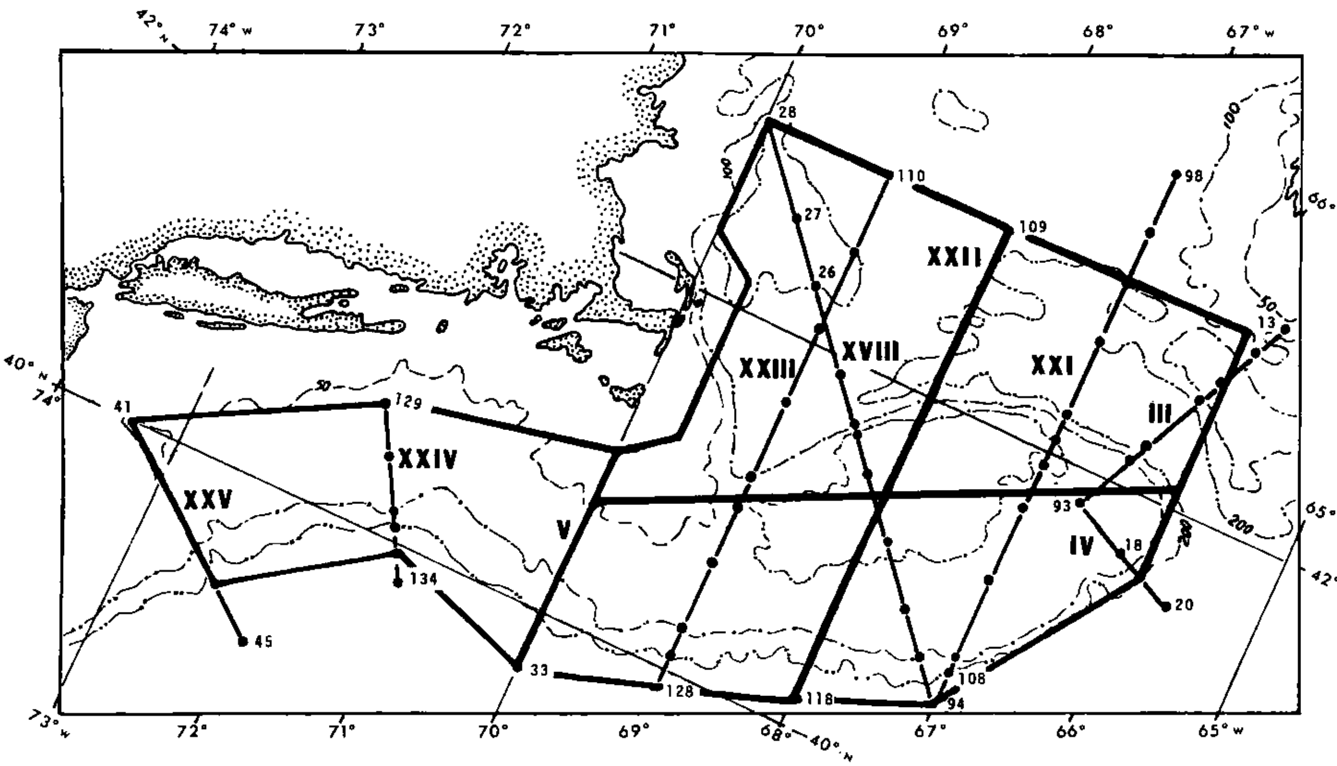

Fig. 1. A scheme showing the different areas and standard sections from which water temperature data was averaged.

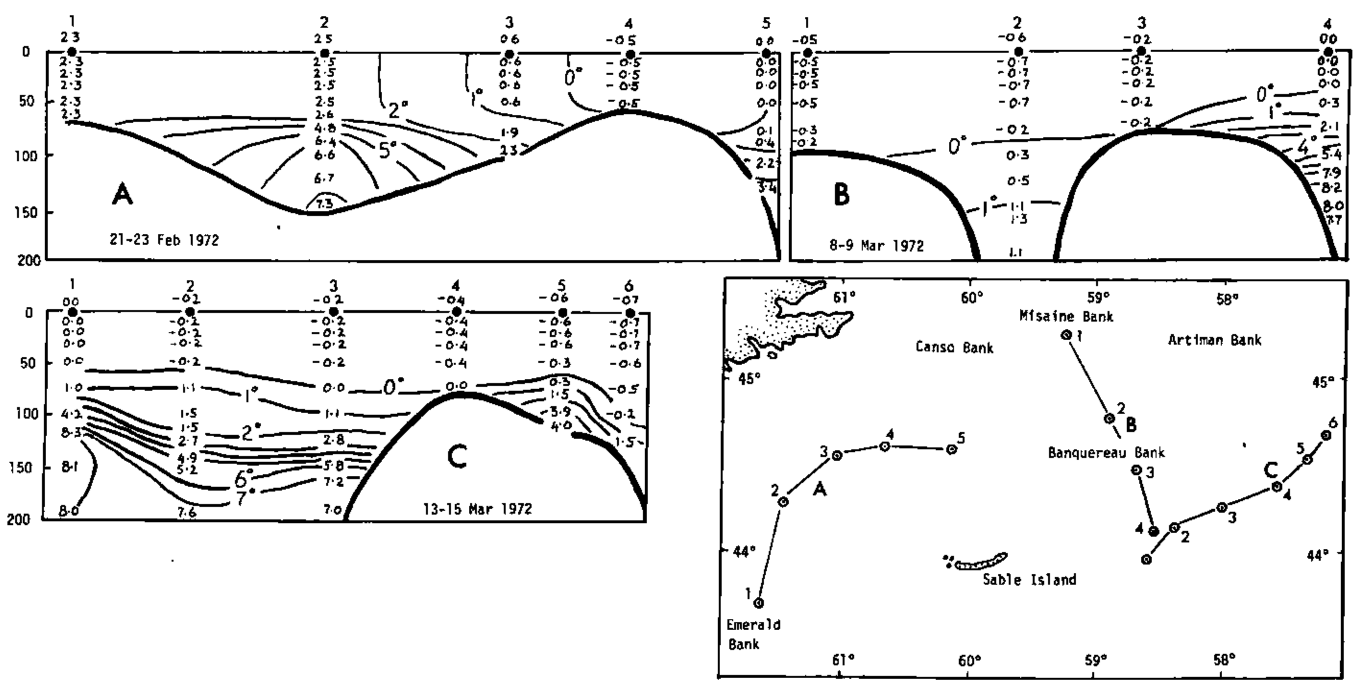

Fig. 2. The distribution of water temperature (°C) along the sections in the eastern part of Nova Scotia in the winter of 1972 (according to the data from RTM *Bakhchisarai*).

The second half of March was marked by a great deal of floating ice, the boundry being along 44°40'N approximately. The northern slopes of Canso, Misaine and Artimon Banks were occupied by floating ice during the whole month. Mean weighed water temperatures within the 0-100 m layer in Cabot Strait were considerably lower in 1972 than in all previous years since 1967 (Table 1). At the same time it should be noted that temperatures of the offbottom layer were very much higher than in the eight previous years. This fact indicates that in the winter of 1972 the intensive inflow of Labrador water paralleled a strong intrusion of Gulf Stream water in the offbottom layer in the area of Cabot Strait.

Thus, abnormally cold conditions were formed in the upper 100 m layer on the Nova Scotia Shelf in the winter of 1972. However, water temperatures below 100 m and in Cabot Strait were the highest in eight years (Table 1).

According to the R/V *Argus* survey data, water temperature distribution in the surface layer of Georges Bank in June 1972 reflects the characteristic features of the end of hydrological spring especially for the central part of the Bank where the temperature of

TABLE 1. Mean weighted water temperatures (°C) in Cabot Strait for the winter periods 1963-65, 1967-72.

Layer	1963	1964	1965	1967	1968	1969	1970	1971	1972
m									
0-30	3.3	4.2	-0.2	3.7	2.4	1.7	3.6	2.5	0.0
30-100	3.0	0.7	0.4	3.2	2.2	1.8	2.9	2.9	1.4
100-bottom	3.5	2.4	2.7	2.8	4.4	3.5	4.8	3.1	6.5

the water column reached 11°-12°C. The areas adjacent on the southern part were strongly influenced by the advection of warm oceanic water. In June 1972, the most intensive and prolonged influence of these waters was observed in the area of 67°W and 70°-71°W. The northern, eastern and northwestern parts of Georges Bank were strongly affected by relatively cold waters from the adjacent area of Nova Scotia. Water of minimum temperatures from 4° to 6°C was predominant here near the bottom. For comparison with the observations in June 1971 the data on the surface and bottom temperatures were averaged using the above scheme (Table 2).

TABLE 2. Water temperature averaged for different parts of Georges Bank for June 1971 and 1972.

		Longitude West			Northern part of Georges Bank	Southern part of Georges Bank
Layer	Year	74°-70°	70°-68°	68°-66°		
0	1971	11.6	12.5	11.7	11.4	12.9
	1972	16.4	12.7	11.2	11.2	12.2
Bottom	1971	2.3	7.3	7.6	7.0	7.9
	1972	9.5	8.4	8.6	7.6	9.3

From Table 2, average surface temperatures in June 1972 appeared to be lower over the eastern part of the area as compared with 1971. The western half of the Bank were then 0.2°C higher. Calculated average temperatures for the northern and southern parts of Georges Bank, were lower in 1972 than in 1971. Bottom temperatures exceeded significantly the 1971 level. The analysis of the temperatures over the whole water column from surface to bottom gave comparative data for the three sections XV, XXIV and V only (Fig. 1). Results of the comparison are given in Table 3.

TABLE 3. Mean water temperatures along the sections in the eastern part of the American shelf in June 1971 and 1972.

Years	XXV	XXIV	V
1971	11.6	10.2	12.1
1972	11.5	13.7	12.9

Table 3 shows that water temperatures from the surface to the bottom along sections XXIV and V in the area of 70°-71°W were considerably higher in 1972 than in 1971. This is probably due to the strong influence of the above mentioned Gulf Stream advection. To the westward in section XXV, June 1972 temperatures were very close to those for 1971. Thus, surface water temperatures were lower in June 1972, while bottom temperature was considerably higher, as compared with 1971.

From an analysis of water temperature fields obtained in August, the pattern of temperature distribution on Georges Bank was analogous to that in June. As before, there was upwelling of the intermediate layer into the area of South Channel, an inflow of Nova Scotia water onto the eastern slopes of the Bank, and advection of Gulf Stream water to the southeastern and southern slopes. Simultaneously the distribution of coastal water with higher temperature and lower salinity became more intensive in the western part of the Gulf of Maine and between 70° and 74°N. Surface coastal waters and intermediate layer upwelling resulted in the formation of a zone with strong temperature gradients in the area of South Channel. The southern slopes of the Bank were characterized by weaker horizontal gradients in August than in June, the latter being observed in the same areas between 67° and 68°W and near Witch Canyon. Temperature distribution in the offbottom layer was also marked by a weaker advection of Gulf Stream waters in the south as compared with June, by availability of gradient zones on the northwestern slopes and by water inflow to East Channel.

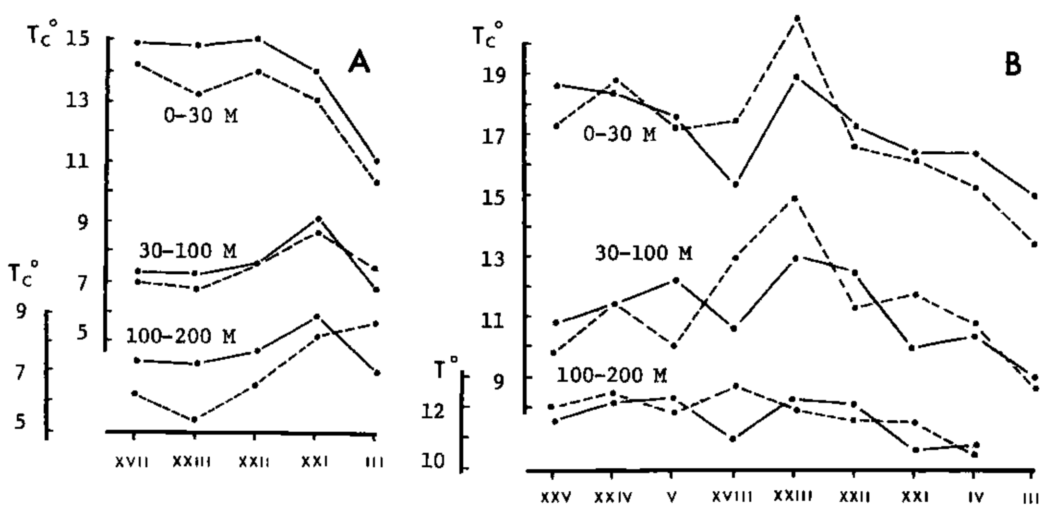

Fig. 3. Mean water temperature (°C) along standard sections in August 1972 and 1971 for the 0-30 m, 30-100 m and 100-200 m water layers on Georges Bank and on the eastern part of the American Shelf.

---- 1972 – northern part of Georges Bank.
—— 1971 B – southern part of Georges Bank.
III, IV, V and so on – numbers of the standard sections.

For comparison with the thermal conditions in August 1971 the data on water temperatures were averaged by standard sections for the 0-30 m, 30-100 m and 100-200 m layers in the northern and southern parts of Georges Bank. From these data water temperatures were plotted (Fig. 3). As can be seen from Fig. 3, in August 1972 in the northern part of the area (north of shallow waters) the temperatures within all layers, except the off-bottom layer along section III, were lower than in 1971 and in southern part (south of shallow waters) the decreae of temperature was not observed everywhere. Mean temperatures in the same parts of the southern area, where the advection of Gulf Stream water was rather pronounced, appeared to be somewhat lower than in August 1971. As the plots demonstrate, this is typical for the areas from 67°W to 19°W. Thus, as a result of water temperature analysis in August, it can be concluded that in the northern part of the Bank the temperature was lower within the 0-100 m layer, while below 100 m it was the same as in 1971. As for the southern part, the decrease of water temperature was marked mainly within 0-30 m, while in the layer from 30 m to the bottom it was higher than in 1971.

Analysis of surface water temperature fields in October 1971 and 1972 indicates a lower level in October 1972. This difference is strongly pronounced over the whole area of Georges Bank. In the central part of the Bank temperatures were from 14° to 15.5°C in 1971 and fluctuating from 12° to 14°C in 1972. In October 1972 temperature gradient zones were absent on the southern slopes where they were dominant in 1971. Advection of Gulf Stream water was observed only near Witch Canyon. Surface temperatures in the Gulf of Maine varied from 9.3°C in the east to 13°C in the west, while in October 1971 it was not below 10.5°C except for two local regions affected by intermediate upwelling, i.e. South Channel (9.3°) and the area north of Cape Cod (8.9°). In the offbottom layer the temperature difference was due to more dispersed horizontal gradients in the north and east in 1972 than in 1971. The bottom temperatures in the western part of the Gulf did not differ from those in 1971 (6.3°to 6.9°C), but were found over a more extensive area. Temperatures near the bottom in the deepwater depression of the Gulf of Maine which can be used as an index when evaluating the extent of transformed waters due to inflow from the Gulf Stream into the Gulf of Maine, were 0.5°C lower in October 1972 than in October 1971. The eastern part of the Gulf was also characterized by lower temperatures similar to the eastern part of the American shelf between 70° and 72°W. In order to compare October temperatures in 1971 and 1972 water temperatures were averaged by anology with the June data. The results are given in Table 4.

TABLE 4. Water temperature averaged for different parts of Georges Bank for October 1972 and 1971.

Layer	Year	Longitude West 72°-78°	70°-68°	68°-66°	Northern part of Georges Bank	Southern part of Georges Bank
0	1971	17.5	14.0	13.7	13.1	15.7
	1972	15.2	13.1	11.4	11.6	13.2
Bottom	1971	12.9	10.1	10.4	9.4	12.1
	1972	11.5	9.6	9.8	9.4	11.1

As can be seen from Table 4, water temperatures on the surface and near the bottom in October 1972 were on the average 1.3° lower than in 1971.

Discussion

Summarizing the above, it can be concluded that, in the winter period, abnormal hydrological conditions on the Nova Scotia Shelf were due to the intensive advection of the cold Labrador waters from Cabot Strait and their extension to the areas in depths to 100 m. Numerous concentrations of young herring observed by RTM *Bakhchisarai* in the areas of Nova Scotia and Georges Bank can probably be explained by these abnormal conditions. The reuslts of observations made in June, August and October 1972 in the Georges Bank area indicated lower temperatures in the surface layer than in 1971, while October observations revealed lower temperatures in 1972 in the offbottom layer. In June and August 1972, water temperatures in the offbottom layer in some parts of Georges Bank were greatly influenced by the advection of Gulf Stream water and were consequently higher than in 1971, but on the whole, thermal conditions in 1972 were lower than in 1971.

As demonstrated above, temperature variations in the area under survey caused by various factors (seasonal variability and advection) were not the same throughout the water column. In June 1972 surface temperatures were lower and bottom temperatures were higher than in 1971, in August the situation was the same and in October similar temperature changes took place both in the surface and offbottom layers. Therefore, when determining the level of thermal conditions of the area, it is most desirable to have several indices characterizing the temperatures of the main three water masses, that is surface, intermediate cold layer, and bottom water. In addition, such indices should be obtained for each season, as well as for each part of the area.

Circulation East of the Grand Banks, 1973

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INTRODUCTION

Each year the International Ice Patrol conducts oceanographic surveys along the edge of the Grand Banks of Newfoundland. This is the region where the cold core of the Labra or Current (<2°C and <34.3°/oo) meets and mixes with the warm, saline waters of the North Atlantic Current (>12°C and >35.5°/oo). Due to the boundary formed on the west of this region by the Grand Banks and the permanence of the two current systems, the area is quite well inderstood on the average. Thirty-two years of dynamic height data have been combined and are presented in Fig. 1. The data shows the mean characteristics of the circulation east of the Grand Banks. The Labrador Current follows the slope of the Grand Banks closely with a typical speed of 30 cm/sec. The North Atlantic Current maneuvers its way 50-150 miles off the Banks with a permanent meander near the Newfoundland Rise and has a current speed of 30-50 cm/sec. Between these two current systems is a region of mixed water forming a dynamic low, or trough. Averages, on the other hand, are inadequate in areas such as this where the variance of the physical parameters is high. The real or synoptic world is not as predictable. In the more synoptic data, eddies of all sizes appear and meanders become more complex and numerous.

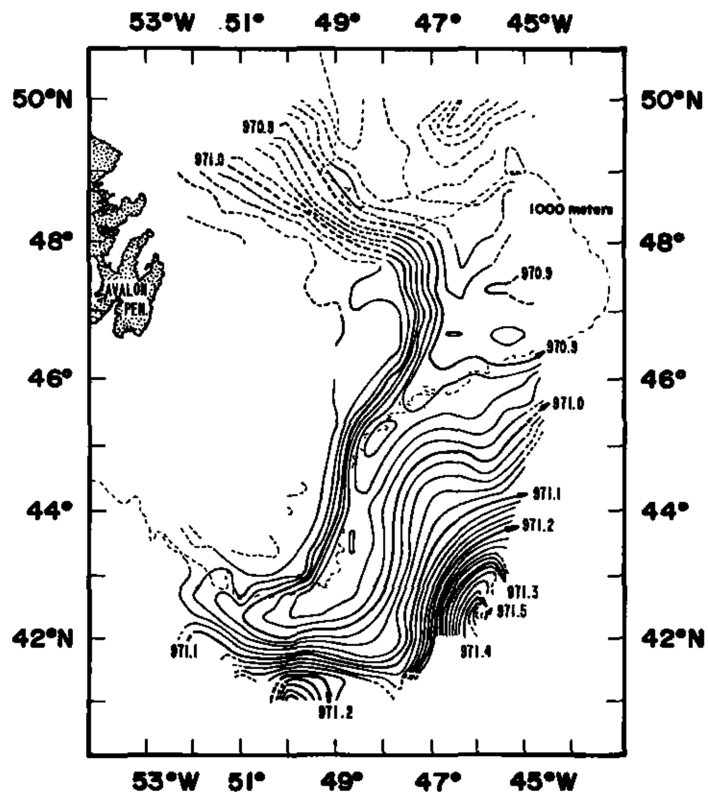

Fig. 1. Average dynamic topography for April computed from 32 years of data.

[1] *Present address:* US Coast Guard Research and Development Center, Avery Point, Groton, Connecticut, USA 06340.

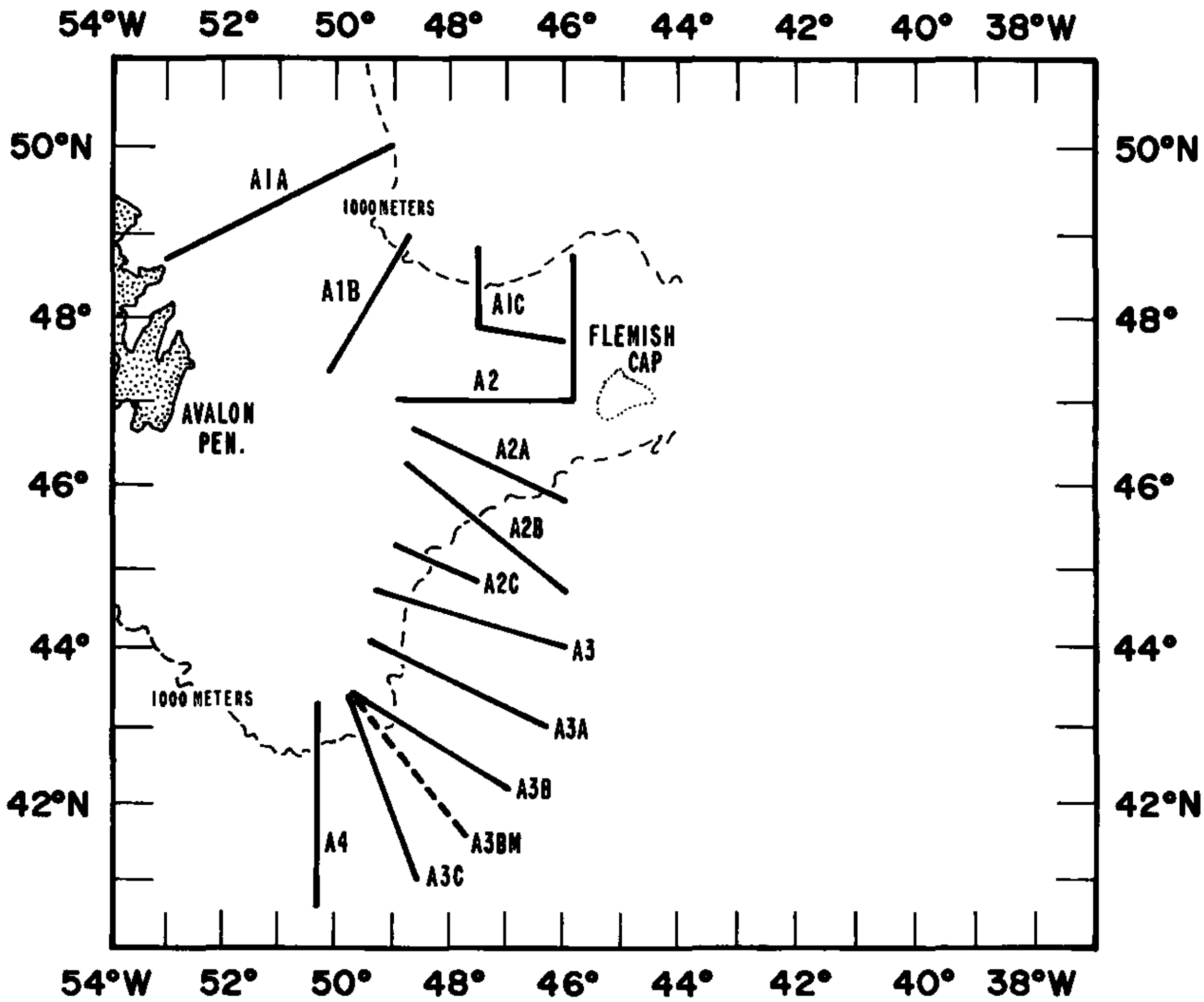

Fig. 2. International Ice Patrol standard sections.

In 1973, International Ice Patrol made three oceanographic cruises which surveyed from the Tail-of-the-Bank in the south to Flemish Cap in the north. On the first two cruises, stations were occupied along International Ice Patrol standard sections selected from those shown in Fig. 2. The selection was made on the basis of all available ice information. On the third cruise an abbreviated survey was taken along standard sections together with three intensive surveys of a 60 by 60 nautical mile square. Three hundred fifteen oceanographic stations were occupied using a Plessey salinity-temperature-depth system together with a digital recording system. These data were then used to construct charts of dynamic topography which are roughly equivalent to the actual topography of the sea surface, the lines of equal dynamic height being approximately parallel to the surface current and their separation being inversely proportional to the current speed.

First Cruise (17-21 April 1973)

The first cruise revealed a current regime (Fig. 3) in which the North Atlantic Current was about 40 miles further north than usual and was running directly against the Tail-of-the-Bank. This in turn forced the Labrador Current up on the banks proper. The volume transport of the Labrador Current was reduced to $0.3 \times 10^6 m^3$/sec. on Section A4 from a value of $3.5 \times 10^6 m^3$/sec. on Section A3B. The dynamic topography presented in Fig. 3 indicates that the excess Labrador flow was incorporated in a large pool of cold (<5°C), slowly moving water centered on 42°-50°N, 48°-20°W. In the center of this cold pool was a strong, anticyclonic eddy with a velocity of 28 cm/sec. This situation was confirmed by the presence, during this period, of large numbers of icebergs around 43°N which did appear to be moving further southward. The eastward limits of this cold water region were ill defined because operational considerations precluded additional stations on the

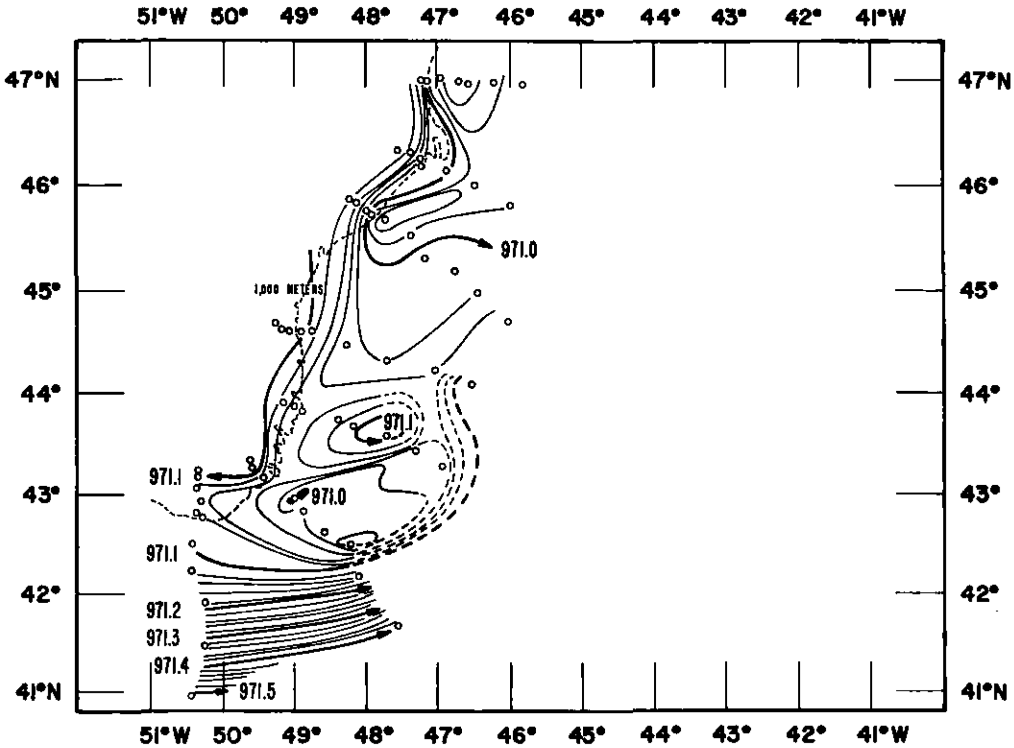

Fig. 3. Dynamic topography for April 1973, relative to 1,000 dbars.

east. At the northern end of this dynamically flat region, at 45°-40°N, is an area where a large portion of the Labrador Current branches from the main flow and moves eastward south of Flemish Cap.

Second Cruise (18-24 May 1973)

By 18 May the situation had dramatically changed (Fig. 4). The North Atlantic Current remained far to the north against the Tail-of-the-Bank keeping the Labrador Current up on the Banks. The May flow of the Labrador Current had increased, from the April cruise period, at Section A4 to $1.0 \times 10^6 m^3/sec$. In the same period the flow upstream at Section A3C was $2.0 \times 10^6 m^3/sec$. or more than $1.5 \times 10^6 m^3/sec$. less than in April. The most visible change was the appearance of a meander of the North Atlantic Current which had an amplitude of 120 mm and a wave length of 90-100 mm. Just to the north of the anticyclonic lobe of this meander was an anticyclonic eddy which had nearly the same dynamic characteristics as the one seen in April. Its surface speed was 23 cm/sec. It was tempting to say that they were one and the same, but they were definitely different because the latter had a thermohaline structure a full 2°C higher and 0.4°/₀₀ more saline. What was seen here was a situation developing which was important for the transport of both water and icebergs across an oceanic frontal system. At nearly the same time, in late May, the southernmost iceberg was at 40°40'N, 49°W, well south of the North Atlantic Current. What happened here was that the anticyclonic eddies had detached themselves from the main stream and moved north and east and the cyclonic eddies had detached and moved southwest. If icebergs are in the cyclonic part of the eddy when it separates they will be transported across a strong easterly flowing warm current and be free to move toward the south and west until they melt.

To the west it can be seen that the area of reversal for the Labrador Current has moved 60 to 80 miles further south than it was in April and that a cyclonic eddy existed at 43°N, 49°-20°W.

Third Cruise (June-July 1973)

In June and July only a brief general survey was made (Fig. 5). In its place, three intensive surveys were made of a 60 mile square centered at 44°-20°N and 48°-30°W (Fig. 6-8). Approximately 50 stations were taken in 3-4 days on each survey, and the surveys were

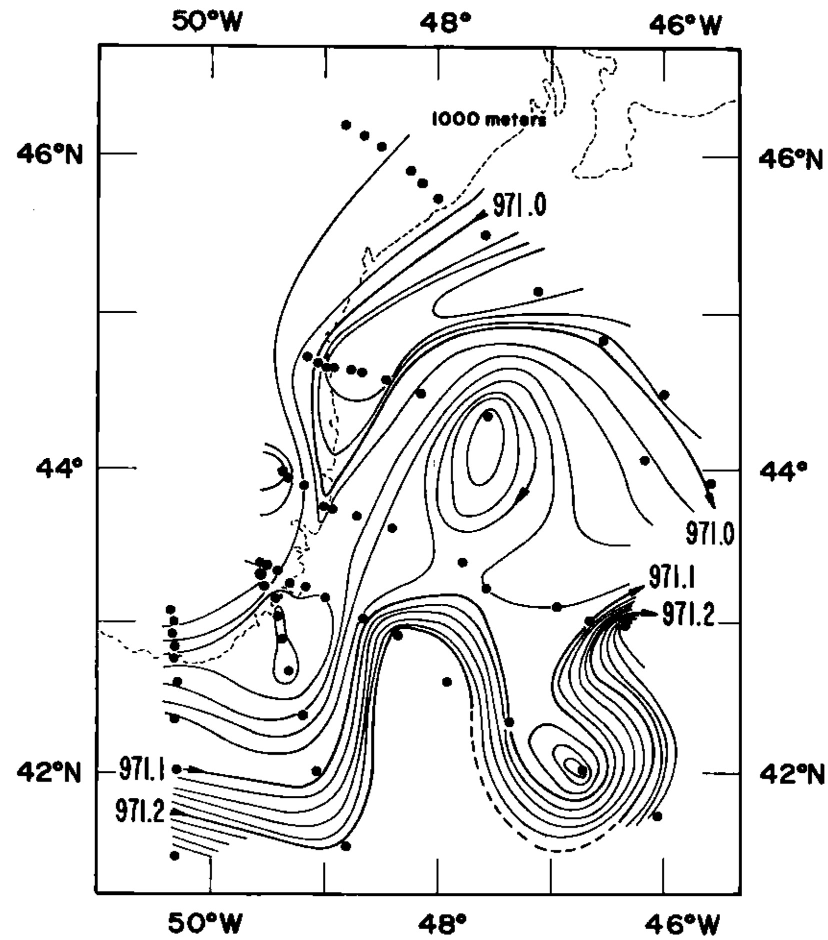

Fig. 4. Dynamic topography for May, 1973, relative to 1,000 dbars.

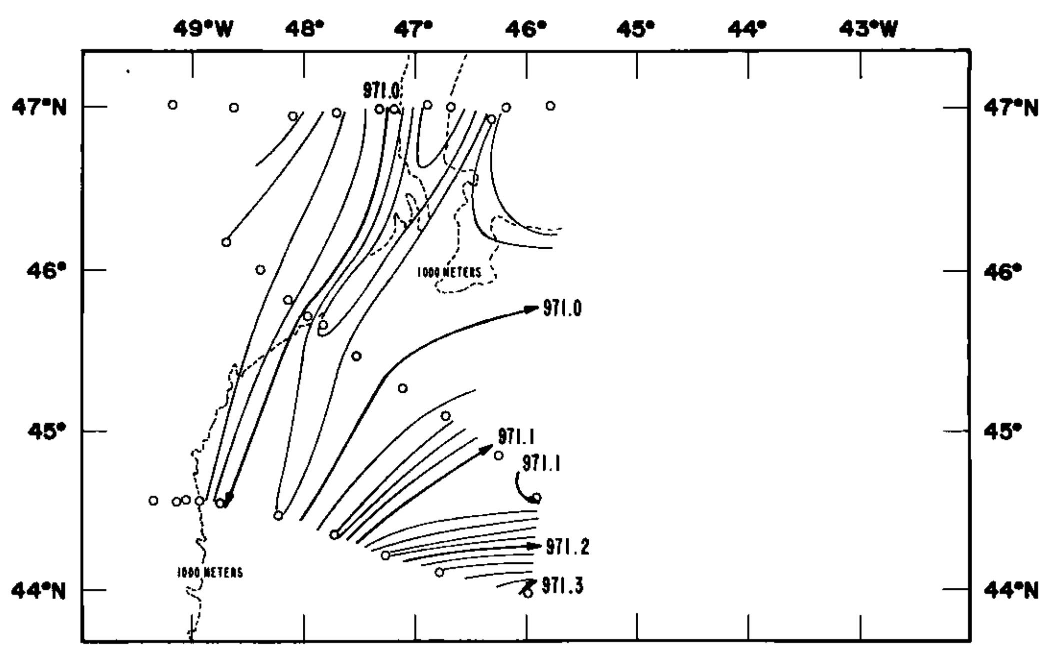

Fig. 5. Dynamic topography for June-July 1973, relative to 1,000 dbars.

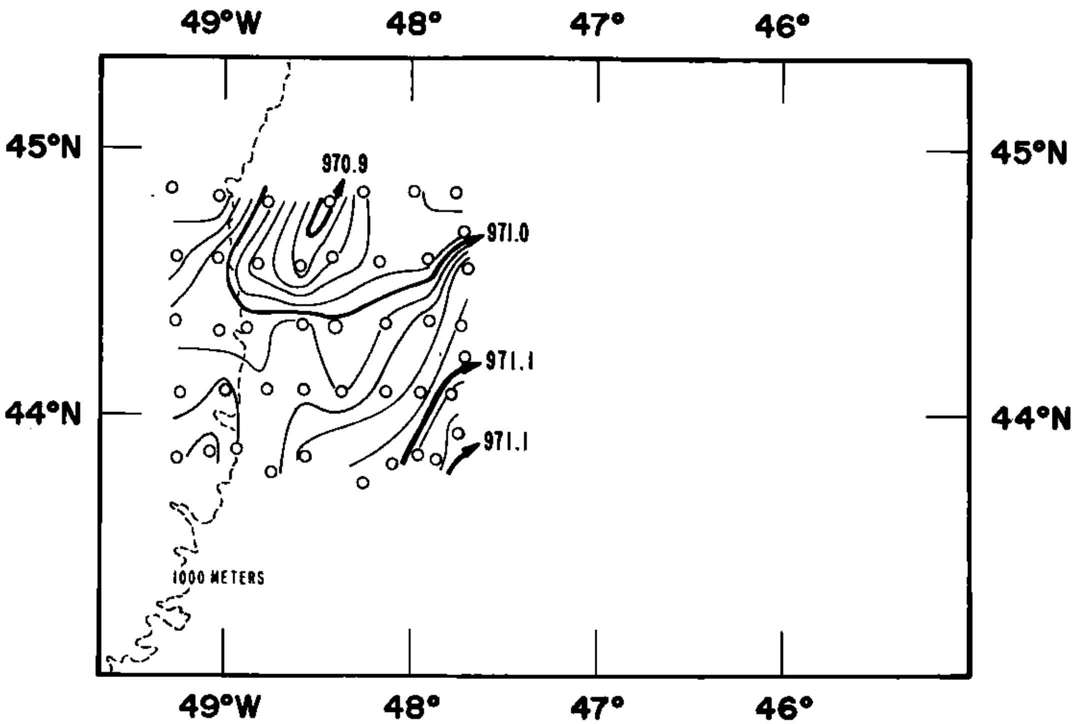

Fig. 6. Dynamic topography for Intensive Survey I, June 1973, relative to 1,000 dbars.

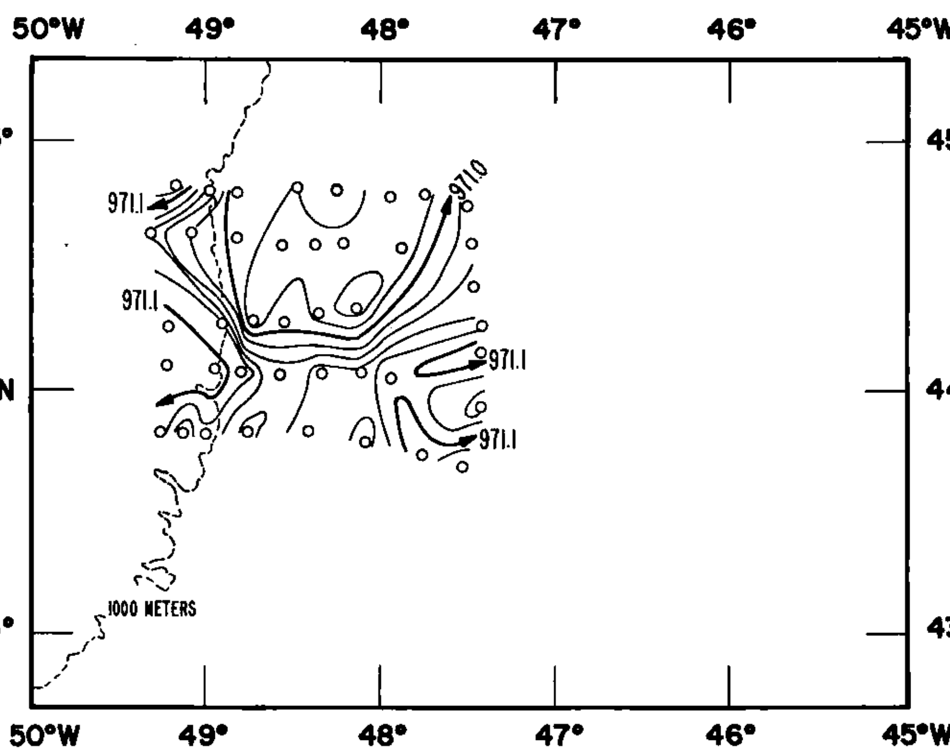

Fig. 7. Dynamic topography for Intensive Survey II, June 1973, relative to 1,000 dbars.

separated by 4 or 5 days. These intensive surveys were made in order to verify a numerical model of the Labrador Current being developed by Cdr. Kollmeyer of the US Coast Guard. The surveys fortuitously covered the region where the Labrador Current was entrained by the North Atlantic Current system. The major feature here, the reversal of the Labrador Current had moved to the southly 27 miles between Surveys I and II. This amounted to approximately 1 mile/day. The detail obtained in these surveys was great compared to the structure displayed by the more conventional survey taken between intensive surveys II and III, although the general pattern matches the northern portion of intensive survey III well.

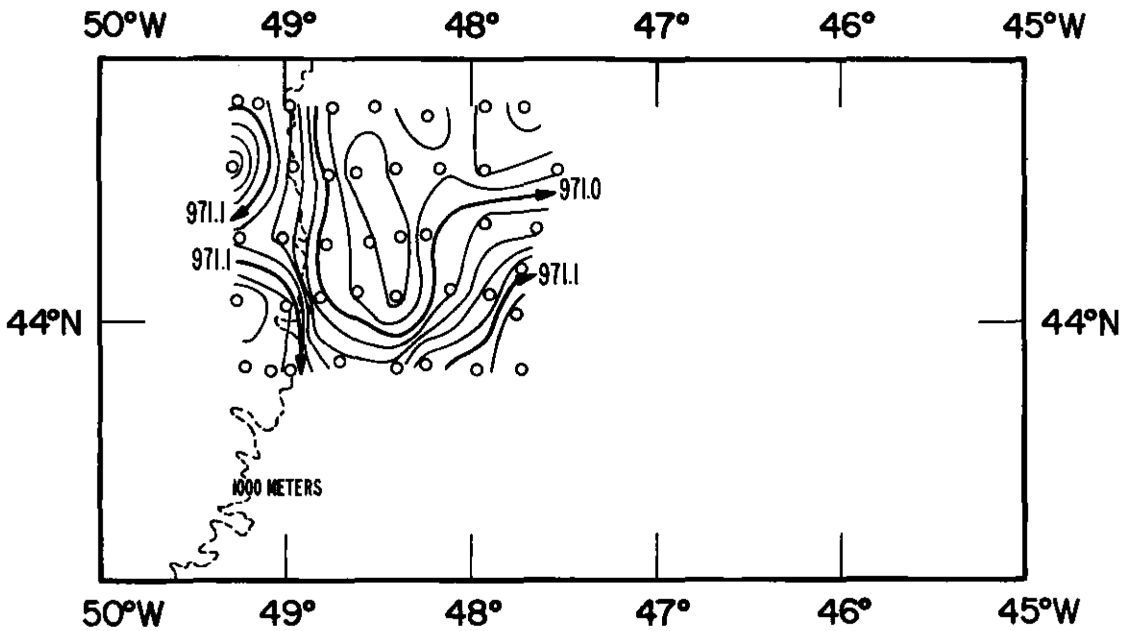

Fig. 8. Dynamic topography for Intensive Survey III, July 1973, relative to 1,000 dbars.

Direct Current Measurements

Since the early 1930's the International Ice Patrol has been conducting oceanographic surveys in the area of the Grand Banks, with the objective of computing surface currents for iceberg drift determination. The method used to compute these currents has relied on the geostrophic assumptions, chief among which is that a level of no motion exists. International Ice Patrol has used the 1,000 dbar surface as the reference surface since the beginning.

In an effort to evaluate the validity of the assumption that there was no motion at 1,000 dbars, Ice Patrol initiated a direct current measuring program to determine the current velocities under the Labrador Current. In 1973 two moored current meters (Geodyne Model 850), using subsurface floats, were deployed under the Labrador Current, approximately 40 m above the bottom. The meters were set to record in the interval mode with a burst of 15 samples every 15 min.

The first meter was moored at a depth of 879 m 44°-13°N and 48°-52°W on 13 April and recovered on 14 May 1973. The second meter was moored on 18 May at 951 m depth at 45°-33°N and 48°-16°W and was recovered 30 June 1973. The data records were complete for both meters and all components appeared to have functioned properly.

A simple average was taken of the measurements in each 15 min interval, the averaged raw data showing velocities as high as 25 cm/sec for both meters. These data were then smoothed to remove frequencies higher than 0.5 cph., thus reducing noise in the data. The current measurements were separated into two components; one tangential to the slope of the Grand Banks and the other normal to the slope. Positive values indicated northward flow for the tangential component and eastward flow for the normal component. The smoothed data were further treated using a numerical filter to remove frequencies higher than 0.8 cpd. or periods shorter than 30 hours. This removed the diurnal and semidiurnal tidal currents. A difference between the smoothed data and the filtered data was calculated, which contained period of approximately 2 to 30 hours.

These filtered data show a surprising degree of variability. At the first meter position, the current ranged from 14 cm/sec southward along the shelf to a quite unexpected current reversal of about 5 days duration, with a northward flow of up to 2 cm/sec. The mean current for this period was 3.4 cm/sec toward the south. The component normal to the shelf was virtually zero. The periodic residuals presented a rather complex picture. The standard deviations from the mean for the normal and tangential components were ±2.2 cm/sec and ±2.8 cm/sec respectively. The only identifiable periodic component was the lunar semidiurnal tide. Harmonic analysis indicated that there was a 17% probability for the normal component that the coefficients for this frequency could have been generated from random data and a 32% probability for the tangertial. This rather high probability appears to stem from the fact that any baroclinic tides present are intermittent and not "phase-locked" to the forcing of the equilibrium tide.

For the other current meter at 45°-33°N and 48°-16°W the aperiodic current varied from 15 cm/sec southwestward along the banks to a 1 cm/sec northward flow that persisted for approximately one day. The mean current was 5.3 cm/sec toward the southwest. Again the normal current component was small in comparison with the tangential component. The periodic residuals in this case had a standard deviation of ±3.0 cm/sec and ±2.9 cm/sec for the normal and tangential components respectively. As in the previous case the only identifiable periodic component was the lunar semidiurnal tide. In this instance harmonic analysis indicated that there was less than a 1% probability for both the normal and tangential components that the harmonic coefficients could have been generated by random data.

The low frequency fluctuation of the current for both meters were compared with the surface wind field. However, no clear relationship between the winds and the currents at these depths was found.

Surface currents measured during this period in the Labrador Current by the geostrophic method ranged from about 15 cm/sec up to 60 cm/sec southward. This compares with a mean current at depth of from 3.4 to 5.3 cm/sec with values running as high as 25 cm/sec for an instantaneous current. The current, except in two cases, was always southward along the slope. Therefore, geostrophic current calculations in the Labrador Current should be considered as minimums with the actual current speed being 10-30% higher.

Discussion

PAPERS 1-3 (BAILEY, TEMPLEMAN, BURMAKIN)

Dr Templeman: Mr Bailey has noted that, for the surface waters, 1964 and 1968 were cold years and 1967 was a notably warm year. Using data from the St. John's to Flemish Cap line from 1966 to 1968 we have found that, on the Flemish Cap section, in 1967, surface temperatures were above average but the temperatures of the intermediate colder waters of the Labrador Current were close to the lowest of the 1951-71 period, but not as low as in 1972 and 1973. On the Flemish Cap line in 1968, surface temperatures were generally the lowest of the 1951-73 period but in the intermediate colder water of the Labrador Current and in the deeper Slope water related to the West Greenland Current temperatures were mainly above average.

Mr Bailey: We so frequently talk of cold years and warm years and cite them as being related to other observed activities. In fact, most of the time, we are discussing the influence of a particular season in a given year where the real impact occurred. A good example of this is shown in my Fig. 9 where in 1967 at St. John's, Newfoundland, the springtime departures from normal were the lowest and the summertime departures from normal were the highest on record. At St. John's, only in 1964 (cold) 1972 (cold) and 1970 (warm) were the departures from normal all the same sign. On a yearly basis, because of the exceptionally warm summer and autumn, 1967 shows up as a warm year in spite of the record cold spring.

There is another point I would like to make. In my presentation, I discussed the seasonal departures from normal for 1972 (Fig. 2-5). Mr Frede Herman in his paper last year (ICNAF Res.Doc. 73/53) indicated that a sudden climatic jump back to cold conditions had taken place in 1972. This seems to be well borne out by the seasonal departure from normal at Position 7 for the winter (Table 1) and spring (Table 2) seasons. The subtleties of local warming and cooling and the advection of waters from one region to another make this condition less obvious at the other positions with perhaps the exception being Position 3 in the Gulf Stream.

TABLE 1. Seasonal departures from normal (winter).

	Position										
	1	2	3	4	5	6[a]	7	8	9	10	11
1970	-2.1	+0.2	-1.3	-1.0	-0.1	+0.2	+0.7	+0.2	+0.5	+0.3	-0.4
1971	+0.9	-0.2	-0.1	-0.4	-0.9	+0.1	+0.8	-0.1	-0.6	-0.6	-0.5
1972	+1.4	+0.7	+0.8	+0.2	-0.6	+0.0	-2.3	-0.3	-0.5	-0.5	-0.2
1973	+1.8	-0.6	0.0	+0.3	-0.3	+0.1	-2.1	+0.1	-1.2	-0.4	+0.9
1974	+0.7	0.0	+1.7	-1.1	-1.0	+0.7	-3.5	-0.2	-1.4	-0.9	+0.5

[a] Position No. 6 may be erratic due to paucity of data and sea ice conditions.

TABLE 2. Seasonal departures from normal (spring).

	Position										
	1	2	3	4	5	6	7	8	9	10	11
1970	-1.0	+0.8	-0.7	-0.2	-0.7	+0.4	+0.4	+0.1	+0.3	-0.5	-0.6
1971	-0.8	+0.6	-0.1	+0.2	-0.5	+0.2	+0.8	+0.5	+0.4	-0.1	-0.1
1972	+0.8	+0.8	-0.3	-0.2	-0.5	-0.9	-1.5	+1.0	-1.5	+1.4	+0.4
1973	+0.7	+0.1	-0.4	+0.4	+0.1	+0.5	-0.6	+0.3	-0.3	+0.3	+0.5
1974	(+2.5)	(-0.6)	(-2.2)	(+2.0)	(-0.9)	(-0.8)	(-2.7)	(-1.0)	(-2.0)	(-0.1)	(+1.2)

Numerals in parenthesis are for the period of April and May only.

Dr Bumpus: I would like to ask Dr Templeman why the codfish succumb to the extremely low temperatures in the Avalon Channel. Do they not avoid the cold water; do they get trapped, or do they try to accommodate to the lower temperatures?

Dr Templeman: Cod do normally move further offshore and into warmer and deeper water to avoid cold water. However, in the Avalon Channel there are a number of deeper holes into which the cod can be driven, and if very low temperature water comes over these holes quickly and sinks into them, the cod could be trapped. The same is possibly true on some of the western parts of the Grand Bank. If temperatures decrease slowly over an area however, the cod should generally be able to acclimatize themselves to the cold water.

Dr Au: Could spawning activity, that may have left the fish more susceptible to low temperatures, have been involved in this mortality?

Dr Templeman: The reports of cod deaths around the Grand Bank were in May. This is the middle of the spawning period of cod on the western, northern and northeastern Grand Bank. At this time after spawning the cod would have passed through a period of little feeding and of draining of fat, protein and other resources into the eggs and milt which are liberated. I have no information, however, that they are more susceptible to death by cold water at this time.

Dr Ford: The first three papers all point to the presence of marked negative temperature anomalies in the fishery areas of the northern and eastern Grand Bank and positive anomalies on the southern edge of the Bank in 1972 and 1973. Is there any correlation between these anomalies on the one hand and catch statistics on the other?

Mr Pinhorn: The catch per unit effort in the commercial fishery and from research vessel data both showed a decline over the period from 1968 in the St. Pierre fishery and since 1969 in the Grand Bank fishery with a levelling off over 1970-71 but a further decline in 1972 when recruitment should have been high, according to earlier surveys. This decline has been during a period when the mean temperatures at 50, 100 and 150m have showed a significant decrease and it may be that this decrease in temperature has affected the availability of fish to the gear, or affected their distribution.

Dr May: To what extent can air temperatures, which are available at coastal stations over a long term, be used as indicators of oceanic climate over the shelf and slope, and in particular how well do the air temperature records relate to the sea temperature records obtained off St. John's at Station 27?

Dr Templeman: We have more than 100 years of air temperature records at St. John's but only some 25 years of sea temperature data at Station 27. Since 1950, the yearly increases and decreases in sea temperature at Station 27 have agreed well with the air temperature variations, not only for the surface layer but also for the lower layers at Station 27, which is in a depth of 176m. In general, air temperatures correlate well with sea surface temperatures but cannot be depended upon to mirror conditions in lower layers in offshore areas. Sea surface, or upper layer temperatures may occasionally be related to year class strength through the survival of larvae. In the southern Grand Bank area, where surface and upper layer temperatures are relatively high compared with the more northern areas, reductions in sea surface temperature may be more favourable for the survival of cod larvae. The years 1964 and 1968, which in Mr. Bailey's paper were given as cold years in the surface waters produced, notably in 1964, successful cod year classes.

Mr Bailey: As Dr. Templeman has pointed out, sea surface temperatures have an important effect in certain biological and fisheries aspects. If there is a really serious interest in analyses of sea surface temperatures at locations other than those at which I have presented data, I would be willing to undertake such analyses.

Mr Hill: I think we should also consider during this discussion period the research documents by Bryantsev and Sigaev (Res.Docs. 74/51, 74/52). Sigaev's paper is particularly interesting since he relates the increased young herring concentrations on the Nova Scotia Shelf and Georges Bank in the winter of 1972 to the intensification of cold water advection from the Cabot Strait in the 0-100 m layer. What is the relationship between the colder water and the young herring? Is there any reason to expect more young herring in the colder water? We should also note that Sigaev reported that on the southern part of Georges Bank and in the Cabot Strait bottom layer temperatures were higher than normal, indicating an above average Gulf Stream influence. A normal, or slightly above normal, transport in the upper 2,000 m of the Gulf Stream and in the Atlantic Current will also be reported by Reiniger and Clarke in the next Session which indicates that both the Labrador and Atlantic Currents were above normal in 1972.

Dr Cushing: I would think that the abundance of herring larvae is probably more related to changes in productivity than to the increased amount of cold water, although of course temperature and productivity may themselves be interrelated.

PAPERS 4-6 (HILL ET AL., REINIGER ET AL., KUDLO

Mr Hill: It is interesting to note both the range of variability of the Labrador Current and also the consistency of the estimates of transport by the different workers, particularly in the April-May 1972 period. The variability calculated from the United States Coast Guard data – over 40 estimates up to 1972 – is 1-11 × 10^6 m^3/sec, or perhaps if we leave out a few of the anomalously high estimates, 1-6 × 10^6 m^3/sec. Kudlo has calculated that during 1971-73 the range of transport values lay between 0.4 - 9.1 × 10^6 m^3/sec (22 estimates) with only three of the values exceeding 7.1 × 10^6 m^3/sec. He also shows that the transport steadily increased form 3.03 × 10^6 m^3/sec on 10 April (Section 6A) through six sets of observations to 8.64 × 10^6 m^3/sec on 16-17 May (Section 3A) and my mean value of 5.5 × 10^6 tonnes/sec fits remarkably well into his time series.

Dr Needler: Is the variability in the estimates of transport given in these papers due to errors in the use of Helland-Hansen's technique for estimating geostrophic flow over shelf areas? How many of these estimates are associated with current meter measurements to provide a reliable reference level?

Mr Hill: I think the geostrophic calculations have been backed up by current meter results to provide a reference level only in one of these papers, namely the one which I presented. However, in this case we get comparable results in terms of total Labrador transport to using Helland Hansen's approximation, or at least to a modified version of it, which we have found to be applicable to this type of shelf area on the other side of the Atlantic and in similar work in the Rockall Channel.

Lt Scobie: A degree of reliability is inferred by the consistency of the transport values obtained and I would like to add to Mr Hill's comments that the USCG estimate, geostrophically calculated, for the 7-8 April 1972 Labrador transport is 5.2 × 10^6 m^3/sec which also fits extremely well into the Kudlo/Hill time series.

Mr Robe: I think another point which must be borne in mind when considering the reality of the variations in the Labrador Current is that if you are not very careful in choosing the station positions you can wrongly estimate the strength of the current. The point is that the current is very narrow, and care must be taken to avoid missing part of it by faulty station positioning.

Mr Hill: Station spacing is important and I pointed out in my paper that we had missed part of the Labrador Current transport on the northern section which is why we have omitted this value in our estimation of the mean transport. The other two estimates we produced are reasonably close however and are supported by the current meter results.

Dr Templeman: In a previous paper, to which Mr Hill referred, Kudlo indicated a clockwise circulation around Flemish Cap whereas the present paper indicates that the water flowing generally southward past Flemish Cap in the Flemish Channel to the east of Flemish Cap is Labrador Current water and not the northward flowing Slope current.

Mr Hill: There certainly seemed to be a weak anti-clockwise circulation around Flemish Cap during most of our survey rather than the clockwise circulation previously observed by Kudlo and Burmakin, but towards the end of our survey, after 21 April, we recorded a north-westerly residual current at our Station A which is in agreement with the Kudlo and Burmakin circulation, and it may be that this clockwise circulation is the more normal for this vicinity.

Mr Bailey: At this point it is perhaps of interest that in analysing the sea surface temperature in the area just to the east of the area which we are now discussing, it appears that there is an interesting phenomenum where the northern waters flow southward for a period of several weeks at a time to enhance the cooler water of the Gulf Stream counter current. This southward flow is then replaced by a generally eastward flow of the Gulf Stream water for a similar period of time.

Dr Grosslein: Mr Hill has been discussing the hypotheses of Mann and Worthington on the derivation of the Atlantic Current and suggesting that Mann is right. What would be the effect on the fisheries of the Grand Bank if Mann's theory rather than Worthington's is nearer the truth?

Mr Hill: One of the essential differences is the greater transport of water between the two gyres postulated by Mann, i.e. about double the maximum interchange suggested by Worthington of some 10×10^6 m^3/sec. Therefore, if Mann is right we might expect a greater influence in the Atlantic Current of the warm water advection from the Gulf Stream along the southeastern slopes of Grand Bank and towards Flemish Cap, i.e. the area of an important cod and redfish fishery. Similarly changes in the variability of the Gulf Stream might be expected to have a greater impact on these fisheries than if Worthington's theory is correct.

Dr Ford: For many years data has been taken throughout the ICNAF area for the purpose of assessing the environmental conditions in respect of the fishery. These studies do not seem to have thrown very much new light on the cause and effect relationships between the environment and the fishery, particularly in the sense of using hydrographic information as a predictive tool. I believe there is a need for a sophisticated eco-system approach to the design and conduct of the investigation, involving at least the physical oceanographer, the marine ecologist and fishery biologist. These observations support in principle the proposal for a coordinated ICNAF environmental research program put forward by Drs Schlitz and Grosslein. My emphasis, however, is on the special thrust to which they refer rather than large scale monitoring surveys, the value of which remains questionable in terms of the overall cost. However, in the interests of maintaining the continuity of the data record, now extending back many years, the present level of monitoring surveys should be continued.

Dr S.R.V. Durvasula: May I comment on the primary production in this region. Recently I reviewed this aspect in the Canadian Atlantic waters for Dr B Muir and arrived at the following conclusions. During Spring there appears to be a gradient in the northeast-to-northwest axis in the development, with the maximum occurring in the northeastern part of Newfoundland and Grand Bank. Only during Spring the maximum production in the northeastern area coincided with the vertical stabilities of $1{,}000E \times 10^8$ or more. This is not so during autumn.

Dr Templeman: In the western Atlantic, when a biologist is dealing with larval survival and the production of good or poor year-classes, he is almost always lacking the essential temperature, current drift, larval predator and larval food information and the time, areas and quantities of fish spawning which might enable him to determine the critical factors for larval survival. For temperatures and currents, the amount of continuous information necessary for any stock of fish could very likely only be obtained by such devices as moored arrays of buoys on the spawning ground, and the drifting and settling areas of the larvae. Accessory information on the other factors would presumably have to be taken by research vessels.

Dr Ford: What are the critical problems biologists think physical oceanographers need to be looking at?

Dr Cushing: Once the spawning grounds and nursery grounds are well described, the physical conditions can be limited to the region of the larval drift. For example, production might be shown to depend on vertical mixture. In broader terms, the distribution of current systems is of considerable value in elucidating migration routes and hence stock boundaries.

Dr Clarke: Our experience in the Gulf Stream and the Slope Water current shows that moored buoy data cannot be interpreted unless spatial information is available around the mooring site. Thus I feel one cannot use moored buoys alone to understand the movement of water, one must also use ships or aircraft to look at the spatial fields nearby simultaneously, at least on the shelf and banks themselves. Moored instruments in a few of the channels through which certain types of water are known to flow might be useful if such channels could be identified.

PAPERS 7-9 (KUDLO, SCOBIE, ROBINSON ET AL.)

Mr Hill: It seems clear from Lt Scobie's paper that the cause of the increased transport in the Labrador Current in the early summer of 1972 was basically the increased negative anomaly in the Icelandic Low which increased north westerly winds, and also decreased air temperatures, over the Canadian east shelf area during the first half of the year. As well as increasing the southerly drift of the icebergs as Lt. Scobie reported, the increased north westerlies would also increase the water transport itself. The continuous study of these sustained pressure anomalies really is of considerable importance in physical and fisheries oceanography as my colleague at Lowestoft, Dr. Dickson, has pointed out on the other side of the Atlantic. He has been able to relate these meteorological anomalies of pressure systems and the associated anomalous winds to increased salinification of the North Sea and to deep layer Baltic inflow (in other words increased transport of Atlantic water to the European continental shelf) in the physical field and to the failure of the Atlanto-Scandian herring stock, through the delay in plankton production due to increased northerly winds, in the biological field.

Mr Bailey: Lt. Scobie said that the sea surface temperature is a significant factor in determining the number of icebergs that may reach the Grand Banks. However in the confines of the Labrador Current itself it would appear that the yearly variation of the sea surface temperature is not sufficiently variable during the relevant period of the year to cause a variation in the iceberg count. According to the iceberg data published by the International Ice Patrol significant melting does not take place until temperatures have reached about 56°.

Dr Templeman: I should like to see a graph of the number of icebergs against time attached to Lt. Scobie's paper. As he presented it, I noted, as I have previously noted for publication, that the good Grand Bank haddock year-classes of 1949, 1951, 1952, 1955 and 1956 were all in years of very low numbers of icebergs passing 48°N, which may be a useful correlation if the iceberg count is reliable. Can Lt. Scobie tell me how much duplication of numbers of icebergs is likely in the counting system?

Lt Scobie: The icebergs are counted as they pass the 48°N line, and while there may be some duplication from survey to survey, I think the counting system provides a pretty reliable estimate of the number of icebergs getting this far south from year to year, i.e. as a relative index, from year to year, I think it is quite good.

Dr Ford: Every year the International Ice Patrol conducts an excellent and thorough survey of iceberg movements off the Bank. Is it possible that the iceberg distribution itself could be used as a basic indicator of the environmental conditions in respect of the fishery?

Mr Robe: I think it is very difficult to use iceberg distributions directly to give a realistic picture of environmental conditions since there are so many different factors affecting their numbers, distribution and persistence as they move south. Neither do icebergs make good current measuring devices, because firstly they are difficult to re-locate, and re-identify, and secondly, the lack of icebergs is not an indication of a lack of current strength.

Dr Bumpus: Would it be possible to mark them with a blackbox for idnetification purposes?

Mr Robe: Yes, but this doesn't really solve the problem because as the icebergs move south they melt and frequently turn over. As far as visual recognition is concerned, 8/9 of the iceberg is under water and the resulting change of shape above water as it turns over can alter the shape of the iceberg out of all recognition. Since this often happens in fog or at night, reidentification is a tricky problem.

Mr Sandeman: From a position of abysmal ignorance about the subject, I wonder if the resolution of photographs from recent low altitude satellites e.g. ERTS is beginning to approach levels at which icebergs might be detected?

Mr Robe: I am afraid not. The icebergs need to be at least 1/2 mile wide before reasonable definition for identification is achieved.

Mr Bailey: With reference to Dr Ford's remarks about the use of iceberg density as an indicator of cold waters. We have endeavoured to use iceberg reports to outline the areas occupied by Labrador water. The results have been disappointing because the icebergs don't necessarily occupy the full area of Labrador water. However, reports of icebergs have from time to time indicated that colder waters may exist where it was not expected. A close examination of the data frequently supports the supposition that some features of the sea surface temperature distribution had not been adequately described. Without the reporting of icebergs these features otherwise would have been missed.

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